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EDITOR: EDWARD S. DANA.

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VOL. XXXIII—[WHOLE NUMBER, CLXXXIII].

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1912.

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THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. I.—*Physiography of Newfoundland*; by William H. Twenhofel.

Introduction.

Only isolated references to the physiography of Newfoundland occur in the various papers that have been published relating to its geology, while almost nothing has been written on the physiography from the modern standpoint. To obtain some idea of the surface, and its history, the writer, while assisting in a study of the Cambro-Ordovician section of the west and northwest coasts,* made such notes on the physiography as time and opportunity permitted, and as these and the conclusions based upon them may be of value, it has been thought best to publish them. Only the west and northwest coasts have been seen and data relating to other areas have been derived from earlier writers, and in this connection the map by Mr. James P. Howley, Director of the Geological Survey of Newfoundland, has been of great assistance. The complete absence of topographic maps and the lack of detailed facts relating to the geology of much of Newfoundland, requires that many of the statements be couched in general terms.

In treating the subject the major physiographic features are described, and as the Newfoundland surface is to a large degree controlled by rock and structure, these are shown in so far as necessary for interpretation. The chief factors concerned in

* For the opportunity of assisting in this interesting work, undertaken in the summer of 1910, the writer is indebted to Professor Schuchert, for whom he acted as assistant, and Doctor Charles D. Walcott; the work being done under the auspices of the Peabody Museum of Yale University and the Smithsonian Institution. The writer is further indebted to Professors Schuchert and Barrell for having read the paper.

FIG. 1.

FIG. 1. Map of Newfoundland from Rev. M. Harvey's Text Book of Newfoundland History (1890). The northern tributaries of the Humber should extend farther to the north and west.

the production of the surface are examined and the conclusion is reached that the uplands of Newfoundland are the remnants left by dissection of a once almost perfect peneplain. Finally, the relation of the western settlements to the coastal physiography is briefly stated and a few notes are added on the physiography of the Belle Isle coast of Labrador.

General Outline of the Island.

The general outline of Newfoundland is very irregular, the coast being diversified by many bays and headlands, with the result that its length is tripled if not quadrupled. For descriptive purposes the island may be divided into three parts: (1) the main body elongated east and west along the parallel of 48° 30′, terminating on the west in the Long Range Mountains; (2) the northern peninsula, formed for the most part of the Long Range mountains and the foreland to the west; and (3) the peninsula of Avalon on the southeast, almost cut off from the rest of the island by Trinity and Placentia Bays. Possibly a fourth part may be considered as made by the peninsula lying between Placentia Bay and Fortune Bay farther to the west; of which St. Pierre and Great and Little Miquelon Islands may be considered the extension.

Thoroughly land-locked harbors, extending, in the case of many, miles into the land, are common features, some of them, ten to fifteen miles from the sea, having depths of water in their middle portions not permitting the anchorage of ordinary vessels.

Character of the Rocks.

The variations of the rocks in texture, hardness, and solubility have been important factors of physiographic control in the development of the Newfoundland surface, and their regional distribution is as follows:

The northern peninsula of Newfoundland consists of an interior axis formed of metamorphic and igneous crystalline rocks of Laurentian or undetermined age (Howley, Map of Newfoundland). The axis is bordered on the northwest, from Cape Norman to Table Point, by a belt of limestones, generally magnesian, which begin in the Lower Cambrian and extend to about the middle of the Ordovician, having in some places a width of twenty miles and upward. South from Table Point to the Bay of Islands the belt is continued by thick beds of fine-grained shale to coarse sandstone and the coarsest of limestone conglomerate, in which blocks of interstratified limestone and shale with lengths exceeding 250 feet are not uncommon. The bold and rugged coast between Bonne Bay and the north end of Port au Port Bay is composed of basic

igneous rocks, probably intrusive in the sediments. Where these terminate, the limestones, shales, and conglomerates of the north reappear, repeating the sequence but in a reverse direction. From St. George Bay to the southwest corner of the island the rocks are of Carboniferous age, consisting of gypsum, thin coal beds, shale, sandstone, conglomerate, and limestone.

On the east side of the northern peninsula the section, beginning in the pre-Cambrian and extending into the Silurian, consists of alternating zones of limestones, slates, sandstones, and conglomerates,* the belt varying in width from nothing at the south to ten miles and upward at the north.

On the southeastern peninsula the youngest strata are of Cambrian time, consisting of conglomerates, shales, and limestones.† Beneath is the Avalonian series (Proterozoic) of slates, sandstones, quartzites, and conglomerates.‡

The interior is underlain by more or less alternating bands of Paleozoic and Huronian sediments of varied character, Laurentian crystallines, and great masses of post-Ordovician intrusives, consisting of granite, diorite, and trap.§

It is readily seen from this brief description of the rocks that they vary widely, which in consequence leads to decided variations in topographic expression.

Structure of Newfoundland.

No factor has made a more decided impress on Newfoundland topography than that of structure, which in its broader outlines is as follows:

On the coasts of the northern peninsula the beds depart little from the horizontal, Logan‖ stating that "in the great northern peninsula of Newfoundland, instead of undulations, great lines of fracture and dislocations are observed while the strata are but little tilted" and only locally does the dip rise to high angles. On the northern half of the west coast the beds are generally inclined southwestward and the inclination may rise to as high as 30°, while on the opposite side the dip varies around 20° and is south of east.¶ On the east side the faults, with trends approximately parallel to the Long Range, have displacements exceeding 1000 feet and usually the western blocks have been elevated.** On the west side faults strike inland from Hawke Harbor,†† Table Point, and Portland Head,†† the displacement at Table Point being known

* Murray, Can. Geol. Surv., 1865.
† Walcott, 10th Ann. Rep., U. S. Geol. Surv., p. 554, 1890.
‡ Walcott, Bull. Geol. Soc. America, x, pp. 219–220, 1898.
§ Murray and Howley, Geol. Surv. Newfoundland, 1881.
‖ Logan, Can. Geol. Surv., Appendix to paper by A. Murray, p. 45, 1865.
¶ Murray, Can. Geol. Surv., pp. 9–44, 1865.
** Logan, Ibid., pp. 872–876, 1863.
†† Logan, Ibid., pp. 292, 877, 1863.

to be greater than 1000 feet. In every case the eastern mass has been elevated and at Table Point this block has been shoved to the north (relatively), as shown by the bending of the beds on the downthrown mass. The trend is parallel to the Long Range.

At Bonne Bay and the Bay of Islands of the west coast, the beds are in great confusion through fracturing, faulting, and folding. Many of the folds are closed and overturned and to add to the complexities of structure, great masses of basic rocks are intruded into the midst of the sediments. At the former locality, however, the original texture is not greatly modified, for many of the fossils are still present. At the Bay of Islands the forces were of greater magnitude, changing the shales to slates and the limestones to marbles—a change attended by the complete obliteration of all organic remains.

From Port au Port Bay to the southwest corner the strata in places are quite highly disturbed. The dip shows many variations, faulting is not uncommon, and there has been much intrusion of basic igneous rock.*

In respect to the other parts of Newfoundland, Murray† states that the Avalon peninsula and "probably the whole island . . . seems to be ranged in an alternation of great anticlinal and synclinal lines, independent of innumerable minor folds, which present throughout a remarkable degree of parallelism, pointing generally about N.N.E. and S.S.W. from the true meridian, corresponding with the marked indentations of the coast as well as the topographical features of the interior." A great fault "intersects the island diagonally from shore to shore, running in an almost straight line from near the entrance of the Little Codroy River to White Bay."‡ This fault gives off a branch northeast of Bay St. George which courses through Grand Lake to Hall Bay, the southwest arm of Notre Dame Bay.§

It is readily seen from this brief description that Newfoundland structure is extremely varied and should be an important factor of surface control.

Major Features of the Topography.

General surface.—There is no more striking feature in the topography of Newfoundland than the marked parallelism of the peninsulas, reëntrants, lakes, rivers, ridges, and outcrops, which in nearly every case approximate a direction about N. 28° E. Some of the most prominent of the examples are St.

* Murray and Howley, Geol. Surv. Newfoundland, 1873, 1874; Map of Newfoundland, 1904.

† Murray and Howley, Geol. Surv. Newfoundland, p. 139, 1868.

‡ Murray and Howley, Ibid., p. 90, 1866.

§ Murray and Howley, Ibid., pp. 330–332, 1873.

Mary's Bay, continued northeastwardly by Conception Bay; Placentia and Trinity Bays, and Fortune and Bonavista Bays, similarly aligned; the west and northwest coast, offset and broken at St. George, but still essentially parallel; the east coast of the northern peninsula; the coast of the Avalon peninsula; the intrusive masses, the outcrop of the sedimentaries; the Long Range; the course of the Humber River; Grand and Red Indian Lakes; and Glover Island in Grand Lake.

In general, the surface slopes southeastward. The average elevation of the west coast is about 2000 feet, the northern portion approximating 2100 feet or less, which rises to 2300 near the middle and decreases to 1700 feet near Cape Ray. On the east side of the northern peninsula there do not appear to be any elevations greater than 1200 feet. Along the south coast the height decreases from 1700 feet at Table Mountain to about 1350 feet north of Fortune Bay, and on the peninsula of Avalon the highest point is 1100 feet. An axis of somewhat higher elevations extends from the neighborhood of the Bay of Islands through the middle of the Avalon peninsula from which the peaks decrease in height northeastward and southwestward, but are about equal for any particular locality. These figures of altitude, though significant, do not emphasize the real facts, as they are taken from conspicuous elevations rising above the average highland surface. The decrease in elevation of the highlands southeastward is fairly systematic, averaging a little less than 10 feet to the mile, and two planes placed on the western upland and meeting along a line extending from the Bay of Islands to the Avalon peninsula, if given the average slope of the surface, would very nearly coincide with the summits of the average highlands of Newfoundland; and if projected beneath the sea they would rest on, or slightly above, the immediate sea bottom off the east coast. Through this plane would project numerous conical peaks 100 to 400 feet high, usually formed of igneous rocks. On the west coast the regularity and horizontality of the sky line is striking, but on the east greater irregularity appears to exist, the country being more dissected.

The Long Range.—The Long Range, situated along the entire west coast, with an average elevation of 2000 feet, is the highest range of mountains in Newfoundland. At St. George Bay, where the Codroy–White Bay fault strikes into the land, it is broken and offset to the southeast. Its greatest elevation is in the Lewis Hills, about halfway between the Bay of Islands and St. George Bay, where 2700 feet is reached, an elevation purely local and exceeding by nearly 400 feet the height of any other portion of the range. The range faces the west

with an almost vertical front, in some places reaching the sea; but usually with an intervening foreland. To one approaching Newfoundland from Sidney to Port aux Basques, the most impressive feature is the high flat-topped upland, here rising almost vertically from the sea—the southern extremity of the Long Range. If Newfoundland be observed from the Labrador side, one feature will attract and maintain the attention: the flat-topped upland, standing boldly and prominently in view with a low plain on either side, widest toward Cape Norman way—the northern extremity of the Long Range. The sky line of the Long Range is strikingly horizontal and the appearance of an equal height in all its parts is not a fiction resulting from a distant view, for it remains the same near as well as far, while a very cursory study of Howley's map confirms the evidence of direct observation. At many points in this range are "table mountains." Such is that forming its terminus on the southwest and rising to an elevation of 1700 feet. Here for fully fifty miles parallel to the railroad, which follows the west coast, is the steep western front, rising like a wall, little cut up by erosion and with the top of the wall reaching to one level. On the west side of the railroad, opposite this table mountain, is the triangular block of the Anguille Mountains, built upon the older Paleozoic sediments and rising to a height of 1832 feet, more than 100 feet higher than the mountain to the east. The name of Table Mountain might with justice be applied to this block. At the Bay of Islands is Mount Blomidon, 2125 feet high, with a table top, in the central portion of which is a lake. Table Mountain at Bonne Bay, 2336 feet high, is almost as flat on its summit as a western prairie, the surface rising gently from the margin toward the middle. It has been thoroughly shattered by the movements to which it has been subjected, favoring the formation of angular gravel through sun and frost action, and were it not for a mantle of such gravel a

FIG. 2.

FIG. 2. The Long Range opposite Cow Head. Length 7-10 miles. The lowest line is drawn at sea level, the middle at the top of the timber on the foreland (250' ±), and the upper the summit level of the Long Range (2000'). Drawn from a photograph by Charles Schuchert, the vertical being multiplied by 2. The north is on the left.

bicycle could be ridden with ease on the top of the mountain, a surface stated to have a length of six miles parallel to the coast and four miles in the opposite direction. Its sides are very steep and there are few places where it may be ascended except with difficulty. The summit is almost bare of vegetation and that present consists of dwarfed plants occurring in a few wet places or shallow bogs. The plane of this Bonne Bay

FIG. 3.

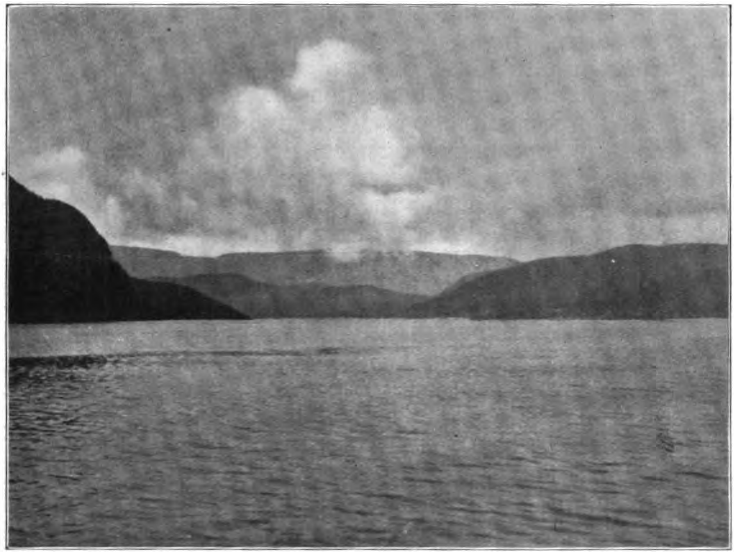


FIG. 3. Table Mountain, Bonne Bay, 2336 feet high. Photograph by Charles Schuchert.

"table" truncates the rock of all the systems in the region, no matter what their structure or character, the elevations rising to, or almost to, its level and there stopping either as peaks, ridges, or "tables."

The Long Range scarp with its elevated valleys.—The slope of the surface of Newfoundland rises toward the west till the summit of the Long Range is reached, where an abrupt drop of between 1500 and 2000 feet takes place. The line of westward-facing cliffs, for the most part composed of crystalline rocks, is almost a straight one, but is broken and offset to the southeast at St. George Bay, south of which it continues in the same direction as a straight line. West of the cliff face the rocks are almost wholly sedimentary and, in general, do not

depart greatly from a horizontal attitude; the general dip is away from the cliff face, but at some localities, as the St. John Mountains and St. George Bay, the beds dip toward the cliff.* In most places, the beds if projected towards the mountains with the dip they have at the sea, would abut against the cliff face; but it is very probable that at its base the strata have an entirely different attitude. Such is the case at Bonne Bay and the Bay of Islands, and Murray† found similar conditions about St. George, where at the foot of the mountains the beds "are usually very highly tilted, inclining in the opposite direction (*away from the mountains*) or vertical."

Erosion has done extremely little to destroy or modify this precipitous westward-facing scarp, its integrity being well preserved. In but a few places like the Bay of Islands and St. George Bay has a large river cut its way to the sea or pushed its head far beyond the mountain face; but many small valleys have been cut in the upper portion of the wall at elevations varying with the region, but averaging one-half to two-thirds the height of the cliff. Most of them flare out near their heads and flow on levels having a lesser gradient than lower down in their courses and nearly all of them appear to head in a wall. At Bonne Bay, where some of these valleys were studied in detail, they present a profile similar to that which follows (fig. 3). The upper level is flat-floored, quite wide, in a few cases one-half mile or more, and at an elevation of about 1200 feet above the sea, or about 900 to 1000 feet below the top of the Table Mountain wall. At Bonne Bay and the Bay of Islands many of the lower elevations rise to about the level of these upper valleys, where they, while not flat-topped, show an older topography on their summits, and at least one table mountain, that at Port au Port, rises to a level slightly less.

Their width is out of all proportion to the small streams flowing in them, which move slowly from one to another of the ponds and lakes commonly present. Lower down in their courses they become a series of rapids and cataracts, enclosed in steep-walled narrow gorges, the descent of which, actual experience teaches is not only difficult but dangerous.

At Bonne Bay the upper valley level affords an easy route of travel from that place to Trout River, a fishing settlement about ten miles farther south on the coast. This route, after the ascent to the upper level has been made, is a really excellent one for vehicles, and the only one that is at all practicable (see fig. 4).

* The dip at the St. John Mountains was judged from the deck of a schooner, but appears so plain that it can hardly be questioned.

† Murray, Geol. Surv. Newfoundland, p. 88, 1866.

Foreland of the Long Range.—Along the northern and western sides of the island, the Long Range is fringed by a foreland of greater or less width. It is widest along the Strait of Belle Isle, approaching twenty miles, but decreases to about ten miles at Port Sanders and holds this width nearly to Bonne Bay. From Bonne Bay to Port au Port Bay the Long Range reaches the sea and the foreland vanishes, but reappears at St.

FIG. 4.

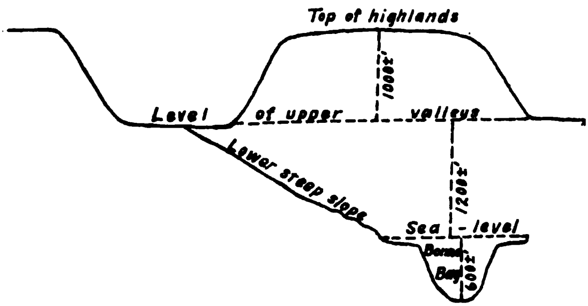


FIG. 4. Profiles of valleys and upland at Bonne Bay. (Diagrammatic.)

George Bay, where both shore and Long Range are offset to the southeast.

The surface of this lower level gives to the observer a decided impression of flatness. Near the sea it is carved into wide and narrow terraces, making the elevation immediate to the shore quite variable, the average being about 75 feet. Inland, elevations rise above 150 feet with many much higher, there being at least three very high blocks of sediments,—Anguille Mountains, St. John Mountains, and Portland Head. Many parts are also low, and it is said that tidal waters go nearly to the mountains at Paul Inlet, Parson's Pond and Portland Creek, at each of which the shores are very low. There also appear to be places where the land is higher on the shore than in the backland, Mr. Thomas House, a fisherman at Table Point, stating that the rear of the foreland in that locality is a marsh considerably lower than is the shore. The presence of glacial striæ at many localities fixes the time of the carving of the surface as pre-glacial.

Uplands of the east and central parts.—Of the east and central parts the writer has no first-hand knowledge, but a study of the published maps and sections and the literature shows that the surface consists of a series of parallel valleys lying in the softer sediments, separated by flat-topped ridges

on which rise local elevations. Professor Schuchert, who visited this part of the island after the writer had left for home, states that "what we saw [on the west] was confirmed in the eastern part of the island and the interior, although the physiographic aspect is a very different one. One sees no such foreland as we saw in western Newfoundland. The nearer one is to the coast the more fiord-like it is";* but even here a section published by Walcott in 1899,† extending from Signal Hill, St. John's Harbor, to Portugal Cove, Conception Bay, shows well preserved flat-topped hills.

On the granite hills of the interior, where crossed by the railroad, "the surface is not a plane; but a gently undulatory one with pointed conical residual hills standing several hundred feet higher,"‡ a description, judging from the reports of Murray and Howley, apparently applicable to most of the interior upland.

Murray states that two great depressions extend across the island, one from St. George Bay through the Humber Valley and Deer Lake to White Bay, the other from St. George Bay through Grand Lake to Hall Bay, their location coinciding with the two great faults described by him.

Rivers and lakes.—The rivers and lakes of Newfoundland are in no respect striking or peculiar with the exception of the Humber and its tributaries. In general, the rivers flow northeast or southwest, parallel to the ridges, along the outcrops of the sedimentary formations. The lakes have their greatest elongation in the same direction. Near the shore the general aspect of the rivers is that of youth, falls and rapids being met with at nearly every turn, with lakes in many places interrupting the course of rapid flow. In the interior the rivers flow in wide, sediment-cloaked valleys, carved in the softer sediments, most of them consisting of chains of lakes separated by intervals of rapid water.

The Humber River with its tributaries, however, more than atones for whatever simplicity is exhibited by its fellows. It has two main branches, one rising far to the south, about twelve miles from the head of St. George Bay, the other about nine miles from the head of White Bay, at an elevation of less than 700 feet. The former flows for about fifty miles in a north-northeast direction, where it meets the latter, which has followed a south-southwest course for more than twenty miles. After the junction the united stream flows almost due west for about ten miles, where another tributary enters from the north-northeast which has two branches; one believed to head less than

* Schuchert, Personal letter dated October 3, 1910.
† Walcott, Bull. Geol. Soc. America, x, p. 221, fig. 6, 1899.
‡ Schuchert, Note book, August 26, 1910.

five miles from the bottom of a western reëntrant from White Bay, while the other has its source about twelve miles from the head of Deer arm of Bonne Bay. Briefly stated, the Humber in two of its tributaries rises less than a dozen miles from the eastern sea at elevations less than 700 feet, with two other tributaries rising but twelve miles from the sea into which it

FIG. 5.

FIG. 5. The Humber drainage. The Long Range lies between the upper river and the coast. 1. Bay of Islands; 2. Bonne Bay; 3. White Bay; 4. St. George Bay. Reduced with some omissions from Howley's map of Newfoundland.

empties, flows entirely across the southern end of the northern peninsula, and then in a steep V-shaped gorge dashes through a mountain range which gradually rises toward the sea and reaches a height of over 2000 feet where the waters of the Humber join with those of the Gulf. In this course the river flows across nearly every character of rock possessed by the island and across such structural features as faults, folds, and igneous contacts. That it is an antecedent river can hardly be questioned.

Peninsulas and bays.—The coast of Newfoundland is diversified by extremely deep bays and bold headlands which on the south and north coasts are elongated in the direction of the structural features already outlined; but on the west and

northwest coasts large bays are not prominent and are rather irregular in their shape and alignment.

Among the large peninsulas of the west coast those of Port au Choix, Cow Head, and Port au Port are the most irregular, the last having a long northern prolongation which finds its continuation in the submerged Long Ledge, a few miles beyond. Each of these headlands is connected with the mainland by a low and narrow neck of accumulated sands and muds which an elevation of the sea-level of but about 25 feet would submerge, converting the peninsula into an island.

The more important bays of the west and northwest coasts are Bonne, St. George, and St. Barbe Bays, the Bay of Islands, and the double reëntrant made by Port Sanders and Hawke Harbor. With the exception of St. George Bay, each of these extends far into the land with deep waters almost to the head. The Bay of Islands and Bonne Bay branch just a short distance from the sea, and then each branch extends back into the land for many miles. Across the mouth of the former there is a string of high islands which are formed of the same kind of rock as exists on each side of the bay. Port au Choix Bay may also be mentioned; not because of its size, but by reason of its narrow entrance and the enormous depth of water within a stone's throw of the shore.

Islands.—Along the coasts of Newfoundland there are many islands, of which only those of the west coast have been seen and to which the remarks that follow alone apply. Those about the western extremity of Belle Isle Strait are very low and of most extravagant shapes. In the broad indentation extending from St. Barbe Bay to Port au Choix there is a succession of low islands and long peninsulas, one of which, Point Ferolle, divides the indentation into almost equal parts. The islands of the northern part are separated from the mainland, here low, by very shallow water. The southern embayment contains sixteen islands, of which the largest is St. John. Deep water lies between this group and the mainland, here formed of the St. John Mountains, an outlier of the Long Range. South from Port au Choix islands are uncommon, if those at the mouth of the Bay of Islands be excepted.

Offsetting of the west coast.—The west coast of Newfoundland shows at four localities,—Point Ferolle, Port au Choix, Table Point, and St. George Bay,—rather striking offsettings, or inland sags of the coast. At each of these places the shore makes a very abrupt bend in an easterly direction, southward from which it continues parallel to the original coastal line. The three northern offsets are parallel to each other, with a southeasterly trend; but the St. George Bay offset trends almost due east and finds its continuation inland in the valley of St.

George River, an almost straight line. The Table Point sag has a thousand-foot fault at its back, Logan has described a fault at the back of the Port au Choix offset, while numerous faults are known about St. George Bay, at the back of which is the great displacement described by Murray. Of Point Ferolle nothing is known.

Evidence of Uplift.

In shaping the surface of Newfoundland, relative elevation has been an extremely important factor, and the evidence for this is given in the paragraphs that follow.

Youthful aspect of the streams.—The rivers of the west coast present a rather striking aspect of youth. Except where the mouths are drowned, all that were seen consist in their lower courses of a series of rapids and falls and flow as a rule in steep-walled gorges. Inland the waters move more slowly, but the numerous lakes with rapid waters between, as described by Murray and Howley, prove the immaturity of drainage.

Terraces.—From the Straits of Belle Isle to the southwest corner of the island, systems of terraces rise like giant staircases

Fig. 6.

Fig. 6. Elevated terraces cut in igneous rock at Beverly Head, north of the Bay of Islands. The uppermost is about 400 feet, the lowest about 20 feet, the very marked one about 75 feet. Photograph by Charles Schuchert.

from the sea. The lowest of these is less than a dozen feet above high water, the highest observed rises above 400 feet. Finely preserved examples of a 25-foot terrace, backed by a 25-foot cliff, exist on the islands north of the Port au Choix peninsula, on the peninsula itself, and at numerous places south therefrom to the Bay of Islands, particularly in the islands at

the mouth. The flat-topped "barrens" of the foreland rising to elevations of about 75 feet or less, are remnants of terraces that are devoid of trees by reason of their swampiness. Around Mall Bay south of Hawke Harbor, three beautifully preserved terraces occur at elevations of about 15, 25, and 40 feet, while still higher may be seen remnants of others, and at Romaine River, near Port au Port, there are five, the highest about 70 feet above the sea.

In the interior, terraces exist around Grand and Deer Lakes, there being at least three at the former at about 5, 15, and 60 feet above lake level, which is 255 feet above the sea; and in the Humber gorge there are also at least three.* There seems no reason for doubting that these inland terraces can be readily correlated with those of the shore.

Barrier beaches.—At several places barriers extend along the sides of shore slopes like windrows of hay in a meadow. Two places in particular where such are rather marked are Current Island, south of St. Barbe Bay, where there are eight, the highest being between 20 and 25 feet above sea-level, and each elevated about 2 to 3 feet above the other; and at Trapper Cove, south of Hawke Harbor, where there are six, with the highest about 20 feet above sea-level, with about 3 feet vertically between one and the next above. These barriers are bare of vegetation and are composed of fresh rock derived from the limestone of the coast, and have, moreover, been there a number of years, appearing to have been formed by successive relative elevations and not by a succession of storms, each of less magnitude than the preceding, as at the latter point they are in a protected place and in the former on the land side of the island.

Delta deposits.—At the mouth of almost every stream on the west coast there is a flat-topped alluvial deposit with the upper surface now standing at an elevation of 60 to 75 feet. The deposits consist of coarse and fine alluvium, the particles rounded, and derived in most cases from the neighboring elevations. They cannot be interpreted as other than delta deposits formed at a time when the strand-line stood relatively higher by at least 60 feet. At many places on each side of the delta flat a terrace continues the level, winding in and out of the reëntrants of the coast (see view 4).

Marine shells.—*Mya arenaria* was observed in clays and sand at two localities on the west coast of Newfoundland,—the modern seacliff on the west side of Port Sanders and in the cliffs of glacial material five or six miles south of Hawke Harbor, being in each case but a few feet above high-tide level. Rock surfaces riddled by lithodomous shells exist at many

* Schuchert, Note book, September 4, 1910.

points on the west coast of Newfoundland to elevations as great as 75 feet, and at Bell Burns Cove, just south of Table Point, Mr. Thomas House stated that in digging a well* on the edge of the marsh, about one-half mile from the shore and 40–50 feet above high tide, he had passed through a bed of "clams."

Fig. 7.

Fig. 7. Trout River, south of Bonne Bay. The 60–75 foot elevated beach and delta are shown with the elevated peneplain in the background. The houses stand on the lowest terrace. Photograph by Charles Schuchert.

Constructions.—No evidence based on human constructions was seen, nor did anyone appear to have any information leading to any conclusions. It is, however, stated by Daly† that along the coasts of Labrador and Newfoundland the fish stages have had to be lengthened again and again, while among the shoals new passages have had to be sought due to the shoaling of the old.

Evidence of Submergence.

Drowned gorges.—St. Barbe Bay, Port Sanders, Bonne Bay, and the Bay of Islands are drowned gorges, the submerged lower courses of once swiftly flowing mountain streams. Each shows all the characters of a river system,—St. Barbe with three main branches and some smaller ones, Port Sanders with two main arms and each with smaller ones, Bonne Bay with three branching arms, and the Bay of Islands with an equal number, each of which fingers out near its head. Each branch of an

* The inhabitants of some of the villages on the west coast migrate annually to the woods on the edge of the marsh fronting the Long Range in order to escape the winds, hence the well.

† Daly, Bull. Mus. Comp. Zool., xxxviii, p. 261, 1902.

arm receives its tributary, a remnant of a dismembered river system. At Bonne Bay and the Bay of Islands the mountains tower over the water with elevations of 2000 feet a mile from the shore, and cliffs rise from the water's edge to nearly a thousand feet, while in the bays the slope descends precipitously from a shallow shelf, where ships may anchor, to depths greater than 700 feet.* The other bays do not have such high margins, though almost equally precipitous, nor do they descend so deep; but depths of 500 feet are not exceptional.

Low islands.—Attention has been called to the numerous low islands on that portion of the coast extending from Belle Isle Strait to Port au Choix. North of St. Barbe Bay these are quite low, many barely rising above the surface of the water, yet with relatively deep water on their inland sides. South from St. Barbe Bay the islands are a little higher and the coast line of the north, if projected south, would rest on the surface of the outer islands and again touch the mainland at Point Rich, the outer extremity of the Port au Choix peninsula. The foreland almost ceases to exist on this portion of the coast, but in its place appear numerous islands with passages between them and the mainland of sufficient depth to float large steamers. The islands are thought to represent the submerged foreland. Between the Bay of Islands and Port au Port the general line of the coast is continued by the submerged Long Ledge and Long Point and the outer margin of the peninsula. The enclosed waters are, in general, quite shallow. An exception is a long narrow trough of 20 fathoms depth that very closely follows the main shore. This bay with its low islands and submerged ledges is also thought to be a part of the submerged foreland.

Submerged folds off the Avalon peninsula.—That the east side of Newfoundland is in a drowned condition appears equally certain. Nearly every river in its lower course enters in a deep bay and the headlands rise precipitously from the water's edge. The parallelism of the peninsulas and bays on this portion of the coast is one of its remarkable features; but equally striking is the submerged topography immediate to the shore with peninsulas essentially similar to those above the water and bays little different from those of the present coast.

Effects of Glaciation.

Along the west coasts erratics are quite common and deposits of till and bowlders exist at several places in considerable thick- see Smith 16

* A part of this depth may be due to glacial overdeepening. How much, however, there are no means of determining, but it is to be noted that the water is more shallow at the entrances than in the interior of the bays. The channels, however, could readily have been filled by the currents that drift along the coast.

nesses, notably in the cliffs about ten miles south of Hawke Harbor. In the interior, along the line of the railroad, glacial debris appears to be more abundant, the mountain slopes being cloaked with material, morainic in character.*

Striæ were seen at numerous localities, generally with a direction closely approximating the trend of the valleys of the place in question. Their presence was noted on top of Table Mountain, at Bonne Bay, in the elevated valleys, and numerous places on the foreland.

The upper system of valleys in the Long Range are decidedly U-shaped while the flared-out heads of some of them strongly resemble the descriptions given of cirques, which resemblance is intensified by the lakes and ponds found in these valleys and held in rock basins. Nearly every one of the valleys shows by the polished rock surfaces that at one time it was filled with the ice, and their precipitous margins are no doubt, in part, due to its work. The surface at many points has a rounded aspect, seen to good advantage near the mouth of the Bay of Islands in the foothills of Mount Blomidon, and to the work of ice may perhaps be ascribed, in part, the gouging out of the deep bays existing around the entire coast although those of the west side are decidedly canyon-like.

That glaciers covered the western side of the island to the highest summits is certain and the same was probably true in respect to the other parts of Newfoundland. The direction of the striæ on the western foreland leads to the conclusion that the ice movement was controlled by the topography, which is in harmony with the belief that " Newfoundland seems to have been a separate area of glaciation. "†

Origin of the Surface Features.

Parallel features.—The presence of great structural lines with a northeastwardly trend finds expression on the surface in control of erosion resulting in parallel ridges and valleys having the same direction as the fold and faults, the softer beds and zones of weakness having been eroded out.

Upland surface.—The accordance of the summit levels of the highlands, the systematic decrease of the elevations eastward, the presence of well preserved flat-topped mountains at many localities with the projected plane of their summits truncating all kinds of structure and rock, the course of the Humber River with its source less than a score of miles from the eastern shore at an elevation of less than 700 feet and its mouth on the opposite side of a mountain range 2000 feet high : these

* Schuchert, Note book. August and September, 1910.
† Chamberlin and Salisbury, Earth History, vol. iii, p. 336, 1907.

are considered evidence of the present dissection, but one time perfection of a peneplain, a plain of erosion of remarkable perfection extending over the whole of Newfoundland.* If the valleys were filled to the level of the average mountain summits the resulting plain would be strikingly perfect, would be 2000 feet high on its western border and pass beneath the sea on its eastern with an elevation of about 700 feet at the shore. This slope probably represents the tilting that has occurred with uplift, which, however, does not appear to have been a simple warping uplift, but by different blocks acting as units, of which the Long Range is perhaps the most conspicuous. On this ancient plain the rivers were free to wander where they would, structure and texture of rock being minimized as factors of stream control. They probably crossed the site of the present mountain ranges and, when the land arose, each stream struggled to maintain its position. The Humber alone carved its way through the rising Long Range blocks and by developing northern and southern tributaries took from other western streams their sources, but thus preserved their waters for the western sea.

Attempts to fix the time of the close of the cycle of erosion in which this peneplain was carved meet with difficulty. The latest rocks involved in the folding that probably initiated the erosion cycle are of Pennsylvanian age and the upper wide and flat-floored valleys are pre-glacial.

In the eastern United States throughout the Appalachians, the existence of an extensive peneplain, completed before the end of Cretaceous time, is now universally admitted and with this base level that of Newfoundland is tentatively correlated, and the period of development and close of the cycle assumed to be the same.

Elevated valleys.—These valleys, situated at altitudes of from 800 to 1200 feet, were probably carved during a period of temporary stability when the land was lower by an amount almost equal to their present elevation. The evidences of an older topography at this level are so evident that any possibility of ascribing them wholly to the work of ice is eliminated and to the work of this agent can merely be assigned their U-shape and greater width. Except that they are pre-glacial their time of origin cannot at present be determined in Newfoundland, but the observations of numerous workers in many parts of the Appalachians have proven the development of a partial peneplain during Tertiary time and these elevated valleys were perhaps a part of that level. There are not sufficient

* Without discussion the writer assumes that this plain owes its origin to subaërial erosion and not marine, considering that the numerous conical residuals and the extensive area support the assumption.

data to discuss the occurrence of this level in other parts of Newfoundland.

Scarp of the Long Range and the foreland.—These two features seem to be causally related in their method of origin and so are considered together. The absence of detailed facts relating to the sediments along the entire base of the cliff renders any conclusion merely tentative. The facts at present known to the writer suggest an origin for each in two possible ways, one far more plausible than the other. These are discussed in succeeding paragraphs.

(1) It may be assumed that the foreland is a plain resulting from marine erosion. The presence of terraces up to 400 feet shows that at one time sea waters covered such portions as are below this elevation. These waters were, however, post-glacial while the foreland's surface existed in pre-glacial time. The general limitation of the foreland to the sediments and its absence when the crystallines are reached favor the idea of its production by marine erosion, which is not supported, however, by the fact that at least three large blocks of the sediments—Anguille Mountains, St. John Mountains, and Portland Head—are left standing on the plain and reach the sea. Its extreme variability in width and almost total absence where the line of cliff reaches the sea, no matter of what kind of rock it be composed, and the steepness and well preserved character of the cliff face in view of the great age required on the assumption of marine erosion render the hypothesis untenable.*

(2) It may be assumed that the scarp is a fault face along which the present Long Range has been elevated. The facts practically proving this idea are: the localization of numerous intrusions along the foot of its southern extension, its remarkable integrity, the actual presence of great faulting near its base at several widely removed localities, and the upturning of the beds where these have been observed at the base of the cliff. The horizontality of the beds, except in the immediate vicinity of the intrusive masses, and their occasional dip toward the mountains find in this idea a ready explanation. On this idea the elevated blocks on the foreland and its variation in altitude are merely due to differential subsidence and elevation, while the bays of St. George and St. John are masses in which the depression was somewhat greater than the rest of the surface, the straight northern coast of St. George being the bounding fault of this bay, which, continued inland, fixed the course of the St. George River. The upper portion of the cliff face, that in which the elevated valleys have been

* This hypothesis permits the assumption that the Long Range may be anticlinal in character. A search for data supporting this assumption yielded negative results.

carved, is the older, while the lower portion may be immediately pre-glacial or even younger, thus explaining its well preserved character. This hypothesis gives to the foreland surface and that of the upraised peneplain a community of origin—both formed when the land was a peneplain and since separated by the faulting up of the Long Range.

See 1688 65 p 51.
Twenhf

Physiographic History.

The present physiography probably took its birth at the close of the period of folding in which the Pennsylvanian sediments were the latest involved. Then was initiated that cycle of erosion resulting in the peneplain, the numerous remnants of which are so well preserved on the flat-topped uplands of the west coast. On the lowland thus created, made almost perfect by the end of the Cretaceous, the rivers, free to wander, ploughed their channels across the site of the present mountains. The close of Cretaceous time is thought to have witnessed the uplift of the highlands of the west coast to an amount equal to about 800 feet, in which movement it is not believed that the foreland participated to a great extent. That it was below the wide upper valleys appears certain, otherwise they should be found engraved on its surface. This uplift inaugurated a new cycle in which these valleys were carved and the rivers once more became adjusted to the structure and assumed their northeast-southwest alignment. Before the completion of this cycle it was interrupted by renewed uplift; but sufficient time had elapsed to bring the topography well on the way toward maturity. When the movement had reached completion, the highlands of the west coast stood about 600 feet above their present altitude, this figure being derived from the depth of the drowned valleys;* and the distance between their summits and the surface of the foreland was increased by an average of about 1000 feet, the latter not participating to a great extent in the elevation. To what extent the east side was affected is not known but that it once was much higher appears certain. Following the elevation the deeply submerged valleys of the west coast were cut. The striking U-shape of the upper valleys and the presence of striæ on the foreland fix the time of uplift as pre-glacial.

Glacial time saw the island under a sheet of ice and then were developed the U-shapes to the upper valleys and the flaring out of the small valleys cut in the cliff face. The topography was softened by the chiseling exerted by the ice on its salients, and many rock basins—the beds of existing lakes—were carved.

* It is possible that a part of this depth may be due to ice cutting below sea-level, although more than 100 feet has been allowed.

Champlain submergence brought a loss of about 1000 feet in the relative elevation of the west coast (the depth of the drowning of the valleys plus the elevation of the highest terrace) and an equivalent amount is assumed for the east. Since that time the island has experienced relative uplift, intermittent in its nature, to an amount equal on the west coast to at least 400 feet. On the east coast the elevation has been differential in character, Daly* stating that the altitude of the highest beach (507 feet on Signal Hill, St. John) decreases northward.

Relation of Settlements to Coastal Physiography.

An extremely close relation exists between the location of the settlements of the west coast and the coastal physiography. The larger settlements owe their existence to the presence of a land-locked harbor, and unless two such harbors are very close together a rather large settlement may be looked for in every one entered. Fish, alluvial deposits, and coves have been the conditioning factors in the location of the smaller settlements north of St. George, a protected cove in which small boats can find refuge and alluvial deposits on which a garden can be made. Most of the streams of the western coast have ancient deltas bordering one side or other of their entrances to the sea, and these places have invariably proved attractive to the settlers as places in which to locate their houses; so that the relation of hut to cove is exceedingly intimate, and one on rounding a headland expects to find a "livier's" home† and rarely is he disappointed, the size of the settlement being correlated with the extent of the cultivatable ground, the protection afforded by the cove, and the excellence of the fishing.

Note on Labrador.

About two weeks were spent on the coast of Labrador, and here on the western end of the Strait of Belle Isle were observed elevated beaches in a magnificent state of preservation, at least eight being seen at one locality, the highest of which was 350 feet above high tide. No careful measurements of slope were made, but the general impression is that they slope to the east, an impression supported by observation made with a hand clinometer. Some of the elevated beaches are covered with myriads of rounded bowlders exactly similar to those of the present shore, only the water being needed to complete the picture of a modern beach from which, however, shells would be lacking, as none was seen in these old beaches.

* Daly, Bull. Mus. Comp. Zool., xxxviii, p. 259, 1902.
† The name "livier" is used on the west coast for an inhabitant of a village.

Above the terraces the Cambrian sandstones and limestones rise to about one level, presenting a flat-topped upper surface which truncates the structure.

A trip was made westward along the coast to Brador Bay, the site of the ancient French settlement of New Brest, to examine the contact between the Cambrian and the gneiss. It was not found, having been completely eroded out by a river

Fig. 8.

Fig. 8. Elevated beaches cut in the Lower Cambrian sandstones and limestones, Blanc Sablon, Labrador. Photograph by Charles Schuchert.

which follows it back into the country, forming a lowland between the Cambrian strata and the crystallines. Inquiry along the coast elicited the information that this depression exists almost everywhere between the Cambrian and the gneiss. If this be correct, then the Cambrian strata form a cuesta and the line of contact with the Laurentians an inner lowland.

Conclusions.

(1) The physiography of Newfoundland owes most of its detail to the structure and texture of the rock which have localized erosion along the zones of the softer sediments and frac-

ture. Still other detail is due to variations in the position of the strand-line and the work of ice.

(2) The extensive distribution of wide flat-topped uplands with local elevations of a few hundred feet, and the horizontality of the summit levels truncating an exceedingly complex structure, show the former presence of a plain at this level, assumed to be a plain of subaërial erosion completed in Cretaceous time and correlated with a similar plain in the Appalachians.

(3) The presence of faulting of great magnitude, the upturning of the beds at the foot of the western face of the Long Range, the extreme straightness of this face, and the elevation on the foreland of large blocks of sediments no different from those contiguous, render untenable the hypothesis that the cliff face and the foreland are due to marine erosion, and practically prove that the Long Range owes its origin to the faulting upward of this block from the foreland's level.

(4) Wide elevated flat-floored valleys along the western face of the Long Range are thought to have been formed in an uncompleted cycle of erosion interrupted by renewed uplift of the Long Range in pre-Glacial time.

Art. II.—*A Hydrocarbon Found in the Diamond and Carbonado District of Bahia, Brazil;* by J. C. Branner.

Among the minerals obtained by me in the diamond washings of Bahia was one known among the miners as "gelo"—ice. The only specimen I have seen was originally about the size of a man's fist, but upon drying it crumbled into angular lumps about as large as peas. It is jet black and opaque; it has a conchoidal fracture, a hardness of 2·2, a specific gravity of 1·51, and is very friable.

The following note was sent me by my Brazilian friend Dr. Alencar Lima of Bahia in regard to this hydrocarbon: "This specimen is from the Caetano Martins diamond washings at Chique-Chique, State of Bahia. The diamond miners call it 'gelo' (ice). It is found in the beds below the diamond-bearing gravels, and it occurs in big pieces, sometimes nearly as large as a man's head. It is solid only so long as it retains its natural moisture, for as soon as it dries it becomes friable in proportion as it dries out. While it is moist it yields a black inky substance, but once dry it does not absorb moisture again."

I have had an analysis made of this material with the following results:

Analysis of a Hydrocarbon from the Diamond-bearing Gravels at Chique-Chique, State of Bahia, Brazil.

L. R. Lenox, analyst.

Water	19·43%
Volatile combustible matter	35·47
Fixed carbon	40·06
Ash	5·07
	100·03%

The ash is mainly alumina with a little silica, calcium, and magnesium.

Tested for solubility it was found to be:

Insoluble in	Soluble in
Cold water	Concentrated sulphuric acid (to a dark brown liquid)
Hot water	Nitric acid (to a dark brown liquid)
Alcohol	Strong potassium hydroxide (to a dark brown solution)
Ether	
Petroleum ether	
Chloroform	
Benzene	
Carbon disulphide	
Hydrochloric acid	

Professor F. J. Rogers of the Physics Department of Stanford University kindly tested the conductivity of this material, but, owing to the small size of the fragments and to its friability, no absolute measure of its conductivity could be made. The general conclusion was reached, however, that it has a low conductivity, about like that of bituminous coal. As an insulator it is not as good as elaterite, Cuban asphaltum, or albertite.

When I first heard of this hydrocarbon I thought it possible that it might be genetically related to the diamonds and carbonados of the region in which it was found. But the size and occurrence of these lumps in recent gravels do not bear out such a theory.

Attempts to obtain specimens of this material from other localities disclosed the fact that the term "gelo" is also applied to material other than hydrocarbon. For example, Mr. Arthur R. Turney of Cachorros has sent me several specimens of what is called "gelo" at the diamond washings at Mosquitos, a few miles south of the city of Lençóes. The materials from near Lençóes, however, are simply hard beds of various thicknesses in the recent gravels. They are made up of sands and water-worn pebbles firmly cemented. They contain no lime and very little iron, and it is therefore inferred that the cementing matter is silica.

Stanford University, California.

Art. III.—*On the Hydrolysis of Esters of Substituted Fatty Acids*; by W. A. Drushel.

[Contribution from the Kent Chemical Laboratory of Yale Univ.—ccxxviii.]

2. *Ethyl Cyanacetate.*

When hydrogen is replaced by halogens in fatty acids the strength of the acids is increased and greater stability of the esters of such substituted acids than of the esters of unsubstituted acetic acid toward the hydrolytic action of water in the presence of a strong catalyzing acid, may be expected. It was shown in a previous paper* from this laboratory that the methyl, ethyl, propyl and isobutyl esters of chlor and brom substituted acetic acids have smaller velocities of hydrolysis in the presence of hydrochloric and hydrobromic acids than the corresponding esters of unsubstituted acetic acid. These results are in accord with the theory that a substance most readily undergoes hydrolysis if it is formed by the combination of a weak acid and a weak base.†

In view of the results obtained from the esters of halogen substituted acetic acids it seemed desirable to make a further study of the rates of hydrolysis of esters of substituted acids. Cyanacetic acid being more strongly dissociated than the monohalogen substituted acetic acids, it is to be expected that ethyl cyanacetate would be even more stable than the ethyl esters of these acids. However the great difference in the rates of hydrolysis of ethyl cyanacetate and ethyl chloracetate under the same conditions of temperature and concentration of ester and catalyzing acid, recorded in Table I, can scarcely be explained on this theory alone. The dissociation constants of acetic acid, chloracetic acid and cyanacetic acid are in the ratio 1 : 86 : 205, and the velocity constants of the ethyl esters of these acids taken in the same order have a mean ratio, calculated from Table I, of 6·5 : 4·2 : 1. The rate of hydrolysis of ethyl cyanacetate is lower than would be expected from a comparison of the dissociation constants of the acids and the rates of hydrolysis of ethyl acetate and ethyl chloracetate.

Preparation of Esters.—The ethyl cyanacetate used in the hydrolysis experiments recorded in this paper was prepared from recrystallized monochloracetic acid by the method of Phelps and Tillotson.‡ Five hundred cubic centimeters of the crude ester were fractioned under diminished pressure and 200^{cm^3} of the pure ester boiling at 95½° C. at a pressure of 12^{mm} were obtained. The ethyl monochloracetate was prepared by boiling for six hours with a reflux condenser a mixture of 100

* This Journal, xxx, 72. † Nernst, Theoretical Chemistry, p. 521.
‡ Ibid., xxvi, 267.

grm. of recrystallized monochloracetic acid and 800^{cm^3} of absolute ethyl alcohol containing 1·25 per cent of dry hydrochloric acid gas. The crude ester was separated from the excess of alcohol by fractional distillation and purified by the method of Phelps and Eddy.*

Hydrolysis in Decinormal Hydrochloric Acid.—Purified commercial ethyl acetate, and ethyl cyanacetate and ethyl monochloracetate prepared as described, were hydrolyzed at 25°, 35°, and 50° C. by making decinormal solutions of the esters in decinormal hydrochloric acid in 250^{cm^3} and 500^{cm^3} flasks fitted with ground glass stoppers and keeping the flasks well submerged in a thermostat during the course of the reactions. The reaction velocity was determined by titrating at intervals 25^{cm^3} of the reaction mixture, diluted with 100^{cm^3} of cold water, with decinormal barium hydroxide, using phenolphthalein as an indicator. For the purpose of comparing the velocity constants the three esters were hydrolyzed under the same conditions of temperature and concentration of catalyzing acid. The velocity constants recorded in Table I were calculated as for monomolecular reactions from the titration formula,

$$K = \frac{2 \cdot 3}{t}[\log(T_\infty - T_o) - \log(T_\infty - T_n)],$$

since cyanacetic and monochloracetic acids are relatively very weak acids in comparison to hydrochloric acid, used as a catalyzing acid, although they are many times stronger than acetic acid. The results of the hydrolysis experiments are given in detail in Table I and in summary form in Table III. It will be observed that the velocity constants for ethyl cyanacetate are very much lower than for ethyl acetate and also considerably lower than for ethyl monochloracetate, in fact, lower than would be anticipated from the dissociation constants of the three acids, acetic 0·0018, monochloracetic 0·155 and cyanacetic 0·370. This is the result which may be expected if the molecules of ethyl cyanacetate exist, at least in part, in polymerized form in dilute acid solution.

Hydrolysis in Water Solution.—Decinormal solutions of ethyl acetate, ethyl monochloracetate and ethyl cyanacetate in water alone were hydrolyzed at 35° and 50° C. and 25^{cm^3} portions of the reaction mixture were titrated at intervals in the manner previously described. In this case the hydrolytic action of water is accelerated only by the acids liberated from the respective esters, a simple instance of autocatalysis. The results were calculated in per cent of ester hydrolyzed at given intervals and are recorded in detail in Table II and in summary form in Table III. It would be expected that the ester which liberates the most strongly dissociated acid would hydrolyze

* This Journal, xxvi, 253.

most rapidly. Table II shows that both ethyl cyanacetate and ethyl monochloracetate are hydrolyzed much more rapidly than ethyl acetate, and that ethyl monochloracetate is hydrolyzed more rapidly than ethyl cyanacetate although cyanacetic acid is a stronger acid than monochloracetic acid. This again is the result which may be expected if the ethyl cyanacetate molecules exist partly in polymeric form in aqueous solution. Suspecting the rapid increase in acidity of the ethyl monochloracetate solution to be partly due to a decomposition of the ester molecule with the liberation of hydrochloric acid, a portion of the reaction mixture was occasionally titrated with decinormal silver nitrate. No measurable decomposition in

TABLE I.

Ethyl cyanacetate in N/10 HCl.

Ethyl acetate		Ethyl chloracetate		Ethyl cyanacetate I		Ethyl cyanacetate II	
T in min.	10^5 K	T in min.	10^5 K	T in min.	10^5 K	T in min.	10^5 K
A. At 25° C.							
0		0		0		0	
180	64·6	75	46·0	120	10·3	180	10·4
300	69·3	1120	46·1	1480	10·4	420	10·9
390	69·1	2700	45·7	2990	10·4	1280	10·1
1260	66·4	4000	46·3	4290	10·6	2730	10·2
1780	67·3	4510	45·1	5675	10·1	4390	9·9
2745	68·5	5770	45·8	7120	9·9	6010	9·8
3195	68·6		45·8		10·3		10·2
	67·7						
B. At 35° C.							
0		0		0			
61	159·2	120	92·7	900	22·4		
120	158·9	240	92·4	1105	22·3		
240	158·8	360	92·4	1300	24·0		
420	159·6	480	92·4	1440	23 2		
540	159·3	1650	88·5	2430	23·3		
715	159·8		91·7	2670	23·2		
	159·3			3780	23·0		
					23·1		
C. At 50° C.							
0		0		0			
5	491·7	20	318·9	20	75·0		
20	496·4	50	321·9	50	78·0		
35	498 6	110	314·9	110	77·4		
50	501·5	180	320·3	180	77·1		
80	500·0	240	321·5	1140	76·6		
110	497·2	300	329·6	2970	76·8		
180	493·2		321·2		76·8		
	496·9						

this direction was observed even at 50° C. The hydrolysis reactions apparently proceeded smoothly according to the following equations:

$$Cl-CH_2-COOC_2H_5 + HOH \rightleftarrows Cl-CH_2-COOH + C_2H_5OH, \text{ and}$$
$$CN-CH_2-COOC_2H_5 + HOH \rightleftarrows CN-CH_2-COOH + C_2H_5OH.$$

TABLE II.

Ethyl cyanacetate in water alone.

A. At 35° C.

Ethyl acetate		Ethyl chloracetate		Ethyl cyanacetate	
T in hr.	% hydrol.	T in hr.	% hydrol.	T in hr.	% hydrol.
0		0		0	
50·5	0	50·5	6·6	30	2·5
111·5	0·3	111·5	15·3	50·5	4·4
163·5	0·5	163·5	24·5	149	13·3
281	1·4	281	41·3	173·5	15·8
385	2·2	385	52·9	201	22·3
476	3·1	476	59·2	240	27·3
573	3·9	573	63·7	294	33·9
				337	38·1

B. At 50° C.

0		0		0	
24	0·2	2	4·2	2	2·1
53	0·4	24	9·9	24	3·4
76	0·5	53	35·4	53	8·8
96	0·7	76	56·7	76	22·4
120	0·9	96	70·2	96	30·3
145	1·2	120	80·6	120	38·8
		145	87·9	145	48·7

TABLE III.

Summary.

Hydrolysis in N/10 HCl

	Ethyl acetate	Ethyl chloracetate	Ethyl cyanacetate
	10^5 K	10^5 K	10^5 K
At 25° C.	67·7	45·8	10·25
At 35° C.	159 3	91·7	23·1
At 50° C.	496·9	321·2	76·9

Hydrolysis in water alone

	T in hr.	% hydrol.	T in hr.	% hydrol.	T in hr.	% hydrol.
At 35° C.	337	1·8	337	47·5	337	38·1
At 50° C.	145	1·2	145	87·9	145	48·7

Hydrolysis in Alkaline Solution.—Decinormal solutions of ethyl cyanacetate in decinormal and fifth normal solutions of barium hydroxide were placed in a thermostat at 25° and 35° C. The decomposition of the ester apparently took place in two

stages. The first reaction proceeded too rapidly to make accurate velocity measurements, having reached an equilibrium in from five to ten minutes with a loss in the alkalinity of the solution nearly equivalent to the concentration of ester used. No apparent formation of ammonia occurred in this first reaction and it no doubt resulted only in the liberation of alcohol and the formation of basic or neutral barium cyanacetate according to the equations:

$$CN-CH_2-COOC_2H_5 + Ba(OH)_2 \longrightarrow CN-CH_2-COO-Ba-OH + C_2H_5-OH, \text{ or}$$

$$2CN-CH_2-COOC_2H_5 + Ba(OH)_2 \longrightarrow (CN-CH_2-COO-)_2Ba + 2C_2H_5-OH$$

Several hours after the alkalinity of the reaction mixture had reached an equilibrium the presence of ammonia became apparent and clusters of needle-shaped crystals began to deposit on the walls of the flasks containing the reaction mixtures. This reaction continued for several days at 35° C. and for more than two weeks at 25° C. with an increase in the amount of crystalline product and ammonia without any increase in the alkalinity of the reaction mixture. This reaction evidently consists of the hydrolysis of the cyanogen group with the formation of free ammonia and barium malonate according to the following equation:

$$CN-CH_2-COO-Ba-OH + HOH \longrightarrow Ba(COO)_2CH_2 + NH_3.$$

The crystalline salt formed in this reaction on analysis proved to be barium malonate.

Summary.—When ethyl cyanacetate is hydrolyzed in decinormal aqueous hydrochloric acid the rate of hydrolysis is much lower than that of ethyl monochloracetate under the same conditions, the effect of the replacement of hydrogen by cyanogen in the acetyl group being a much greater depression of the velocity of hydrolysis than would be expected from the strength of the cyanetic acid generated in the reaction. In water alone the hydrolysis of ethyl cyanacetate also proceeds more slowly than the hydrolysis of ethyl monochloracetate although cyanacetate acid is more strongly dissociated than monochloracetic acid. This marked retardation in the hydrolysis reaction in the presence of the cyanogen group may be due to an effect analogous to what in the esterification reaction is called steric hindrance, or the possibility of the existence of polymerized molecules of cyanacetic ester in aqueous solution may be suggested as an explanation of the retarded action.

In alkaline solution the hydrolysis of ethyl cyanacetate proceeds in two stages. The first is a very rapid decomposition of the ester into alcohol and the alkali cyanacetate, and the second is the hydrolysis of the alkali cyanacetate to the alkali malonate and ammonia.

Art. IV.—*Relations of Missouri River Lœss Mantle and Kansan Drift-Sheet*; by Charles R. Keyes.

For the enormous deposits of lœss which border the Missouri River a glacial origin has never proved a very satisfactory explanation. Their genetic relations have long continued to be one of the most puzzling geologic problems of the region. Regarding them as wind-formed accumulations has only partially removed the difficulties presented. There have always remained many seeming incongruities.

So long and so closely have the southern limits of the drift-sheet, a remarkable belt of Bluff deposits, or lœss, and the course of the Missouri River been associated with one another that something of a genetic relationship between them has been often inferred. The older glacial boundaries practically follow the course of the river from its headwaters to its mouth. In southeast South Dakota a younger drift-sheet also touches the great stream.

Noteworthy among the peculiarities of the lœss of the region are: (1) Its great thickness and conspicuous capping of the bluffs on both sides of the river, a circumstance which early gave it the name of "Bluff Deposit"*; (2) its effectual mantling of the Kansan drift-sheet†; (3) its position in many localities both above and below the drift‡; (4) its greater thickness and higher elevation on the east bluff of the river than on the west side, as first suggested by me in Missouri, and afterwards determined by Bain in Iowa; (5) its extension far forward from the drift-border§; (6) its expansion indefinitely backward over the Kansan drift-sheet‖; (7) its notable non-restriction to the immediate vicinity of the drift-border, but, as recently shown, its extension for great distances westward from the river¶; (8) its deposition on the surface of the country independent of hypsometric conditions**; (9) the multiple terranal character which it displays in many places††; (10) its development beneath the Kansan drift-sheet.‡‡

Since presenting§§ reasons, a decade and a half ago, arguing for an eolian origin of the Missouri River lœss, the conclusions

* Swallow: Geol. Surv. Missouri, 1st and 2d Ann. Repts., p. 69, 1855.

† Todd: Missouri Geol. Surv., vol. x, p. 129, 1896.

‡ Call and McGee: This Journal (3), vol. xxiv, p. 202, 1882; also, Todd and Bain: Proc. Iowa Acad. Sci., vol. ii, p. 20, 1895.

§ Todd: Missouri Geol. Surv., vol. x, p. 132, 1896.

‖ Bain: Iowa Geol. Surv., vol. ix, p. 91, 1890.

¶ Bull. Geol. Soc. America, vol. xxii, 1911.

** Calvin: Iowa Geol. Surv., vol. xi, p. 444, 1901.

†† Wilcox: Iowa Geol. Surv., vol. xiii, p. 716, 1904.

‡‡ Udden: Iowa Geol. Surv., vol. xi, p. 249, 1901.

§§ Keyes: This Journal (4), vol. vi, p. 299, 1898.

then arrived at have been without reserve accepted by Leverett,* Bain,† Shimek,‡ Calvin,§ Udden,‖ and others who have worked in the region. When I first set forth this evidence I was inclined to derive all of the lœss-materials directly from the extensive mud-flats and sand-bars which line the great stream. These sources no doubt are more than ample to supply the necessary matter for the lœss deposits as they appear to-day; yet it now seems probable, in the light of wider investigations, that a greater part of the silty materials comes from more distant localities. Although, at the present moment, quantitative determinations are not available, the volume of wind-borne dusts derived from the dry, upland plains to the west and settling upon and beyond the Missouri River belt must be very great. The latest considerations on this point suggest that not only the contiguous country and the semi-arid belt but the desert regions of southwestern United States are large contributors to the lœss of the Mississippi Valley.

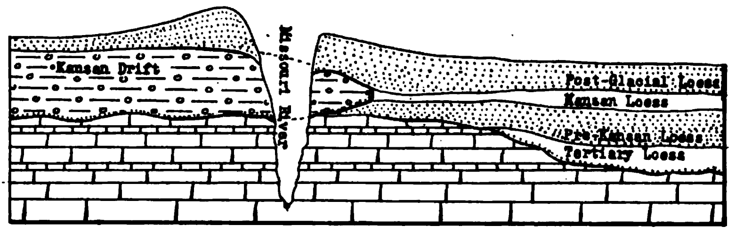
Notwithstanding the fact that it had been long known that the Missouri River lœss extended forward from the limits of the drift, there has been little attempt to ascertain the probable distances. In all physical respects, except perhaps color, the lœss is indistinguishable from the so-called "Plains marls," which so deeply mantle the surface of Kansas and Nebraska; and it cannot be told from the adobe soils of the arid regions that are unquestionably accumulations of wind-blown dusts. The recognition of the identity of the three deposits not only greatly simplifies the consideration of their origin, but it indicates clearly the complete independence of formation of the lœss and the drift. The similarity in physical characters is more than co-incidental; and once the comparison is made of the three soils in the field there remains no hesitancy in pronouncing them identical in origin.

What is really presented by the drift and lœss sections at the Missouri River is a marked overlap of eolian dusts coming from the southwest and of glacial deposits derived from the northeast. In spite of the fact that the eolic formations attain vast development in the region under consideration, their true relations and character are greatly obscured by the vigorous action of the rains, this belt being within the influence of moist climate; they are confused by the presence of extensive glacial formations; they are easily misinterpreted because the typical deposits have never been traced forward from the glacial boundary; and they are not generally critically examined by

* Zeitschrift f. Gletscherkunde, iv, p. 299, 1910.
† Iowa Geol. Surv., vol. ix, p. 91, 1899.
‡ Proc. Iowa Acad. Sci., vol. xiv, p. 247, 1907.
§ Iowa Geol. Surv., vol. xi, p. 442, 1901.
‖ Ibid., vol. xi, p. 248, 1901.

reason of the fact that continental terranes of eolic origin have been little understood. That the real nature of the deposits in question was not inductively established long ago is due largely to the circumstance that they were invariably approached from the side of moist-climate conditions instead of from the side of aridity.

Fig. 1.



It is quite probable, therefore, that towards the Missouri River the Plains deposits represent (1) a Tertiary lœss-section of indeterminable thickness, (2) an extensive Pre-Kansan lœss which also once covered the country east of the river, but of which few traces now remain on account of its profound disturbance by the advance of the ice-sheet, (3) a lœss-sheet equivalent to the Kansan drift that is doubtless everywhere near the glacial border quite thin, (4) an extensive Post-Kansan lœss, which is well developed west of the river covering the surface of the entire region, passing eastward over the Kansan drift-sheet, interlocks with the other drift-sheets in central and eastern Iowa, and continues at the present time to form as rapidly as lœss has ever formed in the past. The several relationships are graphically represented in the accompanying diagram (fig. 1).

Des Moines, Iowa.

Art. V.—*Crystallized Turquoise from Virginia;* by
Waldemar T. Schaller.

Introduction.

A sample of a bright blue mineral, from near Lynch Station, Campbell County, Virginia, was brought to the Geological Survey for identification by Mr. J. H. Watkins. As a few preliminary tests failed to identify the mineral with any known species, a complete study of it was undertaken. The results obtained show that the supposed new mineral is identical with turquoise. The chief interest, however, lies in the fact that this turquoise is well crystallized and it was possible to measure several of the minute crystals and determine thereby the crystallography of the mineral. I am deeply indebted to Mr. Watkins for his kindness in furnishing the material (now deposited in the United States National Museum) and in allowing this description to be published.

The matrix of the specimen consists of irregular fragments of glassy quartz of various sizes, cemented together by thin layers of turquoise crystals. On one side of the specimen the turquoise forms a drusy, botryoidal layer, cavernous in texture and including many small irregular fragments of the glassy quartz. The turquoise, with its many included quartz fragments, polishes well and makes a very handsome ornamental stone.

The spheres, bristling with minute crystals, which form the botryoidal surface, average about two or three millimeters in diameter. The individual crystals rarely are as much as a third of a millimeter long, being usually smaller and much thinner.

General description of mineral.

The turquoise is bright blue in color and vitreous in luster. Cleavage is present, possibly in two directions. The mineral is brittle and has a hardness of about 5, though the minute size and brittleness of the crystals make it difficult to determine the hardness closely. The density of the sample analyzed, determined with a pycnometer, is 2·816, which, when corrected for the 12·57 per cent insoluble material (mostly quartz) present (see analysis beyond), gives for the pure turquoise the value 2·84.

Examined under the microscope, the crystals are clear and transparent and the material is very pure. Pleochroism is distinct, from colorless to pale bluish. Extinction is inclined on all sections and, as verified by the measurements, the crystals

are triclinic. None of the sections showed a good interference figure, though such as were seen indicated biaxiality. One cleavage plate, possibly parallel to *M*(1$\bar{1}$0), showed extinction of 12° against the vertical direction and 12° against the other edge (1$\bar{1}$0 ∧ 0$\bar{1}$1 ?). A different cleavage section, of a rhombic shape, showed extinction values of 5° and 34° respectively, but the orientation of this piece could not be determined. The double refraction of the mineral is high, about 0·04. The refractive indices are about 1·61 for α and 1·65 for γ. Lacroix* gives the value 1·63 for the mean index.

Crystallography.

The crystals are very minute and so closely grown together that it was almost impossible to obtain any suitable for measurement. One complete crystal was found that gave fairly good reflections and the measurements were verified by those obtained on a second, less perfect, crystal. A third incomplete one also yielded a few measurements. The size of the first two crystals measured is as follows:

Cryst. No. 1 .... { ·27^{mm} high (c axis); ·32^{mm} wide (b axis) }

Cryst. No. 2 .... { ·32^{mm} high (c axis); ·40^{mm} wide (b axis); ·12^{mm} thick (a axis). }

The crystals are triclinic and in angles very near to those of chalcosiderite. In fact, the angular values of turquoise and chalcosiderite are so close that the crystallographical elements of chalcosiderite have been adopted for those of turquoise, as the crystals of the latter mineral are but poorly adapted for accurate measurements. Were it not for the knowledge of the crystallography of chalcosiderite (isomorphous with turquoise, see beyond under chemical composition) which we possess, it is doubtful if the orientation of the turquoise crystals could have been interpreted.

The values for turquoise are then:

$$a : b : c = 0{\cdot}7910 : 1 : 0{\cdot}6051;\ \alpha = 92°58',\ \beta = 93°30',\ \gamma = 107°41'.$$

Forms: b {010}, a {100}, m {110}, M {1$\bar{1}$0}, k {0$\bar{1}$1}.

The comparison of the measured angles with the calculated ones† are shown below.

* Lacroix, A., Mineralogie de la France, vol. iv, p. 529, 1910.

† These calculated values are, with one exception, taken from the values calculated for chalcosiderite by Maskelyne, Journ. Chem. Soc., vol. xxviii, p. 586, 1875.

Comparison of measured and calculated angles, turquoise.

Angle	Measured Cryst. No. 1	Measured Cryst. No. 2	Measured Cryst. No. 3	Calculated
$1\bar{1}0 \wedge 100$	45° 12′	......	......	44° 50′
$100 \wedge 110$	31 14	31° 28	31° 25′	31 10
$110 \wedge \bar{1}10$	104 14	.....	104 03	104 00
$110 \wedge 010$*	37 28	38 39	......	40 54
$0\bar{1}1 \wedge \bar{1}10$	107 42	105 15	......	105 36
$0\bar{1}1 \wedge 100$	......	95 33	......	95 45
$0\bar{1}1 \wedge 110$	......	110 00	......	109 36
$0\bar{1}1 \wedge 010$*	......	117 26	......	119 19

* The faces of {010} gave very poor reflections.

FIG. 1.

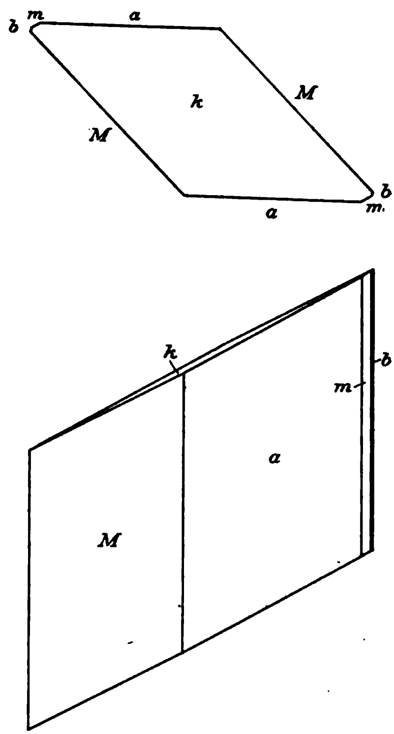


FIG. 1. Turquoise crystal.

b {010}, *a* {100}, *m* {110}, *M* $\{1\bar{1}0\}$, *k* $\{0\bar{1}1\}$.

The forms *a* {100} and *M* $\{1\bar{1}0\}$ are large and striated vertically, *a* generally more striated than *M*. The prism *m* {110} is narrow and striated parallel to the edge (110) : $(0\bar{1}1)$. Between *m* and *k* $\{0\bar{1}1\}$ lies an undetermined small face very

much striated. The clinopinacoid *b* {010} is very small and uneven and gives a very poor reflection. The dome *k* {0$\bar{1}$1} is the only terminal face definitely determined and is strongly striated on crystal No. 1, while perfectly smooth and yielding an excellent reflection on crystal No. 2. It may be that the face of *k* on crystal No. 2 is a cleavage face, as an easy cleavage parallel to this dome was noted by Maskelyne on chalcosiderite.

The habit of the crystals is shown in figure 1.

The pointed appearance of the minute crystals is due to the sharpness of the corners where the intersections of *k* {0$\bar{1}$1} with the faces of the prism zone yield acute points.

Chemical Composition.

Abundant material was on hand for the analysis, which was made on carefully selected pieces free from all impurities except for the quartz. It was found that the mineral is insoluble in boiling hydrochloric acid, but after gentle ignition (when it has turned brown) it is readily soluble in acids. The mineral does not lose any water below 200° and retains its blue color at this temperature. Between 200° and 650° all the water is given off* and the mineral becomes greenish in color. On higher heating the greenish color changes to a brown. The mineral is infusible before the blowpipe but becomes brown.

The average analysis is shown in the table below in the first column, while in the second column is given the same analysis with the insoluble matter (quartz) deducted. The ratios derived herefrom are also given.

Analysis and ratios of turquoise.

	Analysis	Same with insol. matter deducted	Ratios	
P_2O_5	29·84	34·13	·240	2·07 or 2
Al_2O_3	31·91	36·50	·357	3·09 " 3
Fe_2O_3	·18	·21	·001	
CuO	7·87	9·00	·113	·97 " 1
H_2O	17·59	20·12	1·118	9·64 " 9
Insol.	12·57	....		
	99·96	99·96		

The formula derived from the ratios of the analysis is as follows:

$$CuO.3Al_2O_3.2P_2O_5.9H_2O.$$

* Nearly all of the water is expelled below 400°.

Following Penfield's* suggestion as to the relation of the hydroxyl groups, this formula can be interpreted as:

$$CuOH.6[Al(OH)_2].H_5.(PO_4)_4.$$

I believe that this formula expresses the definite composition of turquoise, and a comparison with other analyses shows that this formula is doubtless the correct one.

Among the best analyses of turquoise is the one by Penfield† on material from Lincoln County, Nevada. This turquoise was "of exceptionally fine quality . . . . very fine-grained, of a beautiful robin's-egg blue color, and broke with a smooth fracture. . . . when examined under the microscope, the turquoise seemed to be perfectly uniform, showing no evidence of being made up of two substances . . . it acted somewhat on polarized light." Density given as 2·791.

In the following table are given the analysis of the turquoise from Virginia, Penfield's analysis of turquoise from Lincoln Co., Nevada, and in the third column the composition calculated for the formula proposed:

Analyses of turquoise.

	Virginia	Nevada	Calculated for $CuO.3Al_2O_3.2P_2O_5.9H_2O$
P_2O_5	34·13	34·18	34·12
Al_2O_3	36·50	35·03	36·84
Fe_2O_3	·21	1·44	----
CuO	9·00	8·57	9·57
H_2O	20·12	19·38	19·47
Insol.	----	0·93	----
	99·96	99·53	100·00

The agreement of the three analyses is very close, so that the formula $CuO.3Al_2O_3.2P_2O_5.9H_2O$ expresses definitely the composition of this mineral.

Of the other analyses in which the purity of material is not so definitely known as in the two analyses just cited, there are quoted only those given by Penfield.‡

The high alumina may be partly accounted for by the admixture of a little aluminous rock. By considering some of the iron present as ferrous oxide, FeO, isomorphously replacing the CuO, the analyses agree very well with the values calculated for the composition.

The idea of Penfield's that the composition of the mineral should be expressed as $[Al(OH)_2,Fe(OH)_2,CuOH,H]_3PO_4$ can be more definitely fixed now, as the analysis of crystals of tur-

* Penfield, S. L., On the Chemical Composition of Turquoise. This Journal (4), vol. x, p. 346, 1900.

† Loc. cit. ‡ Loc. cit.

Analyses of turquoise.

	Calculated	Persia. Church	Russia. Nicolajew	California. Moore	New Mexico.		Clarke
P_2O_5..	34·12	32·86	34·42	33·21	31·96	32·86	28.63
Al_2O_3..	36·84	40·19	[35·79]	35·98	39·53‡	36·88	37.88
Fe_2O_3..	....	2·45*	3·52	2·99	....	2·40	4·07
CuO..	9·57	5·27	7·67	7·80	6·30	7·51	6·56
H_2O..	19·47	19·34	18·60	19·98	19·80	19·60	18·49
X....	....	0·36†	....	....	1·28§	·54‖	4·20¶
	100·00	100·47	100·00	99·96	98·87	99·79	99·83
D.....		2·75	2·89	2·86		2·80	

* Given as FeO. The figures would be in better agreement with values calculated from formula if the iron were considered in the ferrous condition.
† MnO. ‡ Includes some Fe_2O_3.
§ Insoluble, 1·15; CaO, 0·13. ‖ Insoluble, 0·16; CaO, 0·38.
¶ Insoluble.

quoise shows that the $Al(OH)_2$, CuOH, and H are present in fixed amounts, namely in the ratio of 6 : 1 : 5. Penfield's own analysis agrees very closely with these figures.*

The crystallographical measurements have shown the apparent isomorphism of turquoise and chalcosiderite. The formula given for chalcosiderite is $CuO.3Fe_2O_3.2P_2O_5.8H_2O$, which differs in form from that proposed for turquoise by one molecule less of water. From Maskelyne's† description of the material used for the analysis of chalcosiderite it seems probable that the sample was contaminated by a little andrewsite, limonite and dufrenite. These all contain less water‡ than chalcosiderite, so that the value obtained is probably a little low and the true amount of water for pure chalcosiderite is higher than that given. The correct formula for chalcosiderite is then more probably to be written with $9H_2O$ instead of $8H_2O$. The isomorphous character of this mineral with turquoise is then clearly brought out.

Turquoise,	$CuO.3Al_2O_3.2P_2O_5.9H_2O$.	triclinic.
Chalcosiderite,	$CuO.3Fe_2O_3.2P_2O_5.9H_2O$.	triclinic.

Summary.

In closing, the three main points developed in this paper may be briefly restated:

(1). Turquoise is triclinic with the crystal form as determined.

(2). Turquoise has the definite composition $CuO.3Al_2O_3.2P_2O_5.9H_2O$.

(3). Turquoise and chalcosiderite are isomorphous.

* Penfield deduced the ratios 7 : 1 : 6 from his analysis, but 6 : 1 : 5 is still closer.

† Maskelyne, N. S., On Andrewsite and Chalkosiderite. Journ. Chem. Soc., vol. xxviii, p. 586, 1875.

‡ Andrewsite has 8·8 per cent, limonite 14·5 per cent, and dufrenite 10·5 per cent water, while chalcosiderite has 15·00 per cent.

ART. VI.—*Crescentic Fractures of Glacial Origin;* by F. H. LAHEE.

THE terms, 'crescentic fracture,' 'crescentic crack,' and 'crescentic cross-fracture,' have been used in the geological literature* to denote certain short, curved cracks which have been observed, usually in sets, on the glaciated surfaces of hard, brittle, homogeneous rocks. Since these fractures bear a constant and definite relation to the direction of ice motion, as indicated by the striae, their origin has been reasonably attributed to glacial action.

During the past summer the writer discovered such an excellent example of these fractures on a ledge brought to his notice by Mr. R. W. Sayles, that he considered it worth while to make a detailed study of them and prepare the results for publication.

The ledge above referred to is one of a group of roches moutonnées of quartzite, situated on the unwooded eastern end of Northey Hill in Lisbon, N. H. According to Hitchcock,† this rock is a member of the 'Coös group' which was listed by him as later than the 'Cambrian clay slate' and earlier than the 'Helderberg quartzites, slates, and limestones.'‡ In his more recent paper,§ this quartzite is represented on the map (plate 43) by a heavy black line in the area of staurolite schist south of Streeter Pond.

Lithologically, this quartzite varies from a rock which is friable, distinctly bedded,‖ and more or less argillaceous, to one that is very hard, massive, and nearly pure. Microscopic sections of the latter phase display a compact mass of angular grains, closely cemented together, with no signs of their original outlines. The compactness of the rock is demonstrated in the section by the sharpness of outline of the glaciated surface which cuts straight across the grains without peripheral crushing (fig. 1, *a–b*). The texture of this quartzite is medium.

Most of the outcrops, especially on the backbone and northern slope of the hill, are of the hard variety. They are of typical roche moutonnée form, with the gentle stoss side on the north. The surface on which the crescentic cracks are best developed, measuring roughly 600 square feet in area, is

* See the following: Winchell, N. H., Geol. and Nat. His. Surv. of Minn., 6th Ann. Rept., pp. 106, 107, 1877; Andrews, Ed., this Journal (3), xxvi, 1883, pp. 101, 102, 1883; Chamberlin, T. C., U. S. G. S., 3d Ann. Rept., 1883, pp. 363, 364, 1883; and, Gilbert, G. K., Bull. Geol. Soc. Am., xvii, pp. 303, 304, 1906.

† Hitchcock, C. H., Geol. of N. H., vol. ii, pp. 275, 317, 318, 1877.

‡ Ibid., p. 273.

§ Hitchcock, C. H., Bull. Geol. Soc. Am., xv, p. 470, 1904.

‖ Stratification: N.55°–65°E., 60°–80°N.

itself a nearly flat stoss slope which has an inclination of about 10° northeastward (in a direction, N.65°E.). Upon all these glaciated surfaces there is a high polish, and numerous, nearly parallel, fine striae trend N.7°–10°E. It is a conspicuous fact that the fractures occur on the northern sides of the roches

FIG. 1.

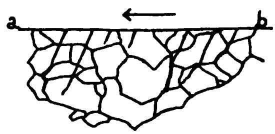


FIG. 1. Section through quartzite showing glaciated surface (*a–b*), direction of ice movement (arrow), and seven crescentic fractures, passing into the rock from *a–b*.

moutonnées, and, further, that they are particularly well developed near the crest of the hill.

The crescentic fractures themselves are grouped in sets, or series, in which the separate members succeed one another at short intervals* in the direction of ice motion, that is, parallel to the striae. Each fracture is concave forward.† Its tracing on the surface of the rock is an hyperbolic-curve‡ of which the *transverse axis* is also the axis of the series to which that crack belongs (and therefore the general direction of ice motion). The *asymptotes* of the curve usually form an angle of about 90°. In any given set all the cracks are not of equal length; there are many short ones for each long one. Hence they are most numerous near the common axis (fig. 2).

The position of the axis is not infrequently marked by a stria, or even by a shallow groove which may be as much as half an inch wide; but such evidences of actual abrasion are not always present.

At the surface of the outcrop, and near the axis, the fracture is distinct and clean-cut and it passes directly through those grains of the rock that may happen to be in its course (fig. 1);

* In one case 60 to the linear inch, parallel to the striae, were counted.

† We use *forward* meaning *with the ice motion*. Andrews, Chamberlin, and Gilbert, noted that crescentic cracks are concave forward and suggested this as a criterion for determining glacier motion. They also observed that, in this respect, these cracks resemble chatter-marks.

In the present locality the shape of the roches moutonnées, the 'drag-lines' on the lee sides of hard rock obstructions, and other features, are sufficient evidence for inferring that the ice advance was from north to south, and that the late Pleistocene local glaciers, which Hitchcock (Geol. of N. H., III, pp. 233–238) describes as flowing north and west from the White Mountains, either did not traverse Northey Hill, or, if so, were no more effective in causing striation and the usual accompanying phenomena here than they were in the region over which he shows they flowed (Bethlehem, etc.).

‡ And therefore not truly crescentic. We use the term *crescentic*, however, following the rule of precedence.

but when traced outward, away from the axis, or downward, into the rock (as seen in microscopic slides), it often wanders between the grains and may jump small intervals and become echelon in habit, as in the case of echelon jointing. Within the rock the fracture surface dips toward the axis, or forward,

FIG. 2.

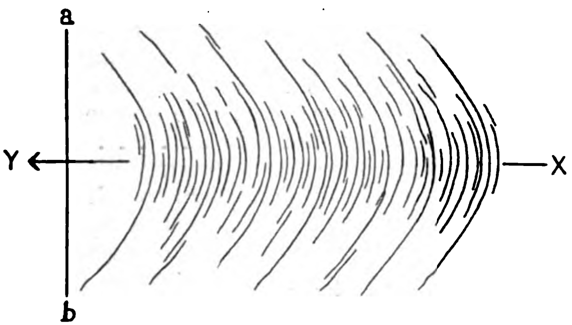


FIG. 2. Plan of a series of crescentic fractures. X–Y is the direction in which the ice advanced. *a–b* is referred to as the 'length' of the longer cracks.

at an angle varying from 60° to 80° (fig. 1). As for their size, individual cracks range up to seven inches in length (*a–b*, fig. 2), although commonly this dimension is between 1/4″ and 2″; and their depth is rarely over 1/4″.

These crescentic fractures, then, are of glacial origin. Gilbert has suggested that they may be due to frictional resistance between the ice and the bed-rock, locally increased by the presence of sand-pockets in the ice-base.* In view of this interpretation it is interesting to observe that the long northern slope of Northey Hill rests upon mica and staurolite schists which are very friable and easily pulverized. We are inclined, however, to attribute the cause to more concentrated action than could result from fine, disintegrated materials, even though they were irregularly scattered. Thus, as evidence for the operation of a pointed or edged tool are (1) the increase in the number of fissures toward the axes of the sets; (2) the dying out of these fractures, not only downward, but also laterally, away from the axes; (3) the frequent association, in a particular manner, of striae and grooves with many of the sets; and (4) the fact that the curves are hyperbolic. According to this view, the tool, in each case, may have been one of the rock fragments with which the ice must have been loaded.

It is worthy of remark that actual contact of this tool with the bed-rock does not seem to have been necessary for the pro-

* Op. cit., p. 304.

duction of the fractures, since many sets are not accompanied by striae or grooves. The scratch associated with a group of fractures denotes merely a greater intensity of the force which first occasioned these fractures; or, in other words, a set of fractures, in itself, is evidence of a less intense force than the set accompanied by a groove.

The distribution of this force within the bed-rock seems to have been tensional. "If the friction on some spot is greater than on the surrounding area, the rock just beneath that spot is moved forward in relation to the surrounding rock through a minute but finite space. This relative movement involves compression about the downstream side of the affected rock and tension about its upstream side . . . . . . rupture occurring when the tensile stress exceeds the strength of the rock,"* and this degree of tensile stress appears to have been arrived at rhythmically, as in the case of chatter-marks, since the crescentic fractures are rather evenly spaced along the axis of any given series. Thus the crescentic fracture resembles the chatter-mark not only in form and orientation, but also in the method of operation of the forces involved.

In addition to the conditions already mentioned, another is indicated by the position of the fractures, especially (and almost entirely) upon gently northward-sloping ledges *on the north side of the hill near its crest.* This is where the gravity component of *resistance* offered by the hill to the onward motion of the ice would be practically nil and would be passing into a gravity component of *assistance* to such motion. To the north of this place the ice was shoved up; to the south of it, the ice was pushed down. Topographic form seems to have controlled, to some extent, the production of the fractures.†

Summarizing, we infer that the conditions important in the formation of crescentic cracks are: (1) a hard, brittle bed-rock; (2) a relatively heavy body of ice moving over this rock; (3) the presence in the ice-base of abundant rock fragments either in contact, or nearly in contact, with the bed-rock; (4) the origin of local tensile stresses within this bed-rock, near its surface, by virtue of frictional resistance between it and the fragments; (5) a gentle slope of the overridden surface toward the direction from which the ice is coming; and (6) the position of this surface near the crest of a hill, that is, between slopes opposed to, and dipping with, the ice motion, and consequently where there should be in process material changes in the relations of the interacting forces.

Harvard University, Cambridge, Mass., Oct. 24, 1911.

* Gilbert, G. K., op. cit., p. 304.

† The writer finds no mention, in the literature, of the exact relation between the topography and other occurrences of the crescentic fractures. The conclusion just presented is drawn from the Northey Hill locality only.

ART. VII.—*The Heat of Formation of Titanium Dioxide*; by W. G. MIXTER.

[Contributions from the Sheffield Chemical Laboratory of Yale University.]

IN 1909 the writer determined the heat of formation of titanium dioxide by the sodium-peroxide method. The value found at that time was 215,600^c.* In an article † which appeared shortly after the writer's, Weiss and Kaiser gave the results obtained by them by burning titanium in oxygen. The average of their experiments is 97,772^c for the heat of formation of titanium dioxide. It will be seen that the value found by them is less than 50 per cent of the value found in this laboratory. This great difference led the writer to attempt the burning of titanium in oxygen.

A preliminary test showed that a platinum tray or cup would not answer for holding the metal in the bomb since the heat of the combustion melts platinum. Furthermore it seemed best to have the particles of titanium separated as much as possible to insure complete oxidation. With this object in view the following method was used. A weighed amount of cotton wool was placed in the hemispherical bottom of a sterling silver bomb having a capacity of 100^{cc}, and titanium in grains or powder was scattered over the cotton. The ignition was by means of a cotton thread suspended from a small wire connecting the electrodes in the bomb. The cotton wool burned instantly and scattered and ignited the metal. After the combustion the titanium oxide was found mostly in one globule sticking to the bottom of the bomb. It was white on the outside but dark colored and crystalline on the fractured surface. In all cases the large globule was hollow, an indication of slight dissociation of the oxide with sudden fall of gas pressure owing to cooling. The titanium used in experiments 1 to 5 was from the same pulverized metal used in the work two years ago. It was ground again in an agate mortar and separated by sifting into two lots, one of grains a millimeter and less in diameter and one of powder. The former was used in the first three and the latter in the fourth and fifth experiments. It was shown in the previous paper that the metal was quite pure. The low calorimetric results obtained with the powdered sample raised the question of its purity and therefore it was analyzed. By the pyrosulphate method 0·4765 gram of the powder gave 97·2, and by solution in hydrochloric acid and precipitation with ammonia 0·2025 gram gave 96·4 per cent of titanium.

* This Journal, xxxii, 393; abstract in Zentralblatt, ii, 180, 1909.
† Zeitschr. anorg. Chem., lxv, 397.

The average is 96·8. Presumably the powder had oxidized. For the sixth and seventh experiments another lump of titanium from the same lot as first used was broken up and only the coarser portion used. It dissolved too slowly in hydrochloric acid, hence a pyrosulphate fusion was made. The result with 0·3109 gram was 100·1 per cent of titanium.

In the first five experiments all of the oxide taken from the bomb was washed to remove a slight amount of silver nitrate present. Then it was dried, weighed, dissolved in molten potassium pyrosulphate and from the fusion TiO_2 was obtained in the usual way. The weight of the TiO_2 obtained less that of the oxide taken was the amount of oxygen required to completely oxidize the oxide. In the sixth and seventh experiments a better method was used, namely: a weighed amount of finely powdered oxide from the bomb was heated until it ceased to gain in weight, the color changing from brown to nearly white.

To find the thermal effect of 32 grams of oxygen combining with titanium in the same ratio as in a combustion in the bomb, let

m_1 = mass of titanium placed in the bomb.
m_2 = mass of the portion used of the titanium oxides taken from the bomb.
m_3 = mass of oxygen added to m_2 to convert all of it into TiO_2.
x = mass of titanium in M_2.
y = total mass of oxygen combined in the bomb.

$$x = (m_2 + m_3) \frac{48 \cdot 1}{80 \cdot 1}$$

$$y = m_1 \frac{m_2}{x} - m_1$$

Let h equal observed heat minus the heat due to cotton, then $\frac{h}{y} 32$ is the heat effect of 32 grams of oxygen combining with titanium under the conditions of the calorimetric experiment. In calculating the heat effect of 32 grams of oxygen in experiments 4 and 5, m_1 is multiplied by 0·968 since the powdered metal used was found to contain 96·8 per cent of titanium.

The table contains the experimental data and the results derived.

The heat effects of 48·1 grams of titanium combining with oxygen in the same ratios as in the bomb are, owing to incomplete oxidation, too low for the reaction $Ti + O_2 = TiO_2$. They prove, however, conclusively that the heat of combustion of

	1	2	3	4	5	6	7 grms.
Titanium (m_1)	1·0374	1·0039	1·1056	1·0000	1·0294	1·5378	1·5605
Cotton	0·1126	0·1283	0·0658	0·0714	0·0858	0·0905	0·0792
Water equivalent of system	1356·	1362·	1429·	1385·	1374·	2762·	2795·
Temperature interval	3·748°	3·587°	3·611°	3·267°	3·446°	2·473°	2·486°
Heat effect	5082°	4886°	5160°	4525°	4735°	6830°	6948°
" " of cotton ..	456°	519°	266°	288°	347°	403°	320°
Heat effect of titanium and oxygen (h) ...	4626°	4367°	4894°	4237°	4388°	6427°	6628°
Heat effect of 48·1 gr. of Ti $= \frac{h}{m_1} 48{\cdot}1$	214,500°	209,200°	212,900°	203,800°	204,500°	201,000°	204,300°
Portion of combustion product (m_2)	1·6024	1·3363	1·7168	1·5118	1·5902	0·6681	grms. 0·6219
Oxygen taken up by m_2 (m_3)	0·0077	0·0196	0·0187	0·0286	0·0243	0·0224	0·0165
Oxygen required to form $TiO_2 = m_1 \frac{32}{48{\cdot}1}$	0·6902	0·6679	0·7357	....	....	1·0231	1·0382
Total oxygen combined in bomb (y)	0·6823	0·6438	0·7157	0·6139	0·6379	0·9400	0·9710
Heat effect of 32 grams of O $= \frac{h}{y} 32$	217,000°	217,100°	218,800°	220,400°	220,100°	218,800°	218,400°

titanium is over 200,000^c. The mean of all of the results for the heat effect of 32 grams of oxygen combining with titanium is 218,500^c. Excluding those of experiments 4 and 5 with the finely powdered metal, the composition of which is not accurately known, the mean is 218,000^c. The last two results are to be regarded as the best, as larger quantities of metal were used and the method employed for finding the amount of oxygen required to complete the oxidation was more accurate than the one used in the other determinations. The last two results give for $Ti + O_2 = TiO_2$ (crystalline) + 218,400^c. This is 1·1 per cent higher than found two years ago by the sodium-peroxide method,* which was 215,600^c, for the heat of formation of amorphous titanium dioxide.

Note on the Spontaneous Oxidation of Titanium in the Air.

The powdered titanium mentioned on page 45 contained not over 97 per cent of metal. Another sample prepared from a lump of pure titanium was ground in an agate mortar from time to time. Then 2·028 grams were left for four months in a small loosely stoppered vial. At the end of this period the weight was found to be unchanged. Analyses were made as follows: One portion, 0·3067 gram, was dissolved in a beaker in hydrochloric acid and a few drops of nitric acid were added and the solution was evaporated to dryness. Then the residue was dissolved in hydrochloric acid. The solution was complete. Finally the titanic acid was precipitated by ammonia, washed, ignited, and weighed with the usual precautions. Another portion, 0·3119 gram, was dissolved in a platinum dish in hot concentrated sulphuric acid, to which a few drops of nitric acid were added. The solution was complete. The analysis was carried out as just described. The two results were respectively 96·6 and 97·1 per cent of titanium.

The 3 per cent of oxygen found by difference corresponds to 7·5 per cent of dioxide or 12 per cent of monoxide of titanium in the powders analyzed. As only clean fragments of pure metal were pulverized, the conclusion is that titanium oxidizes superficially in the air. Since the metal does not gain weight, in time the oxide forms a protective coating. The only statement that I have found in the literature bearing on the question is one in Abegg, III, ii, p. 407, that Schneider found that titanium heated for 15 hours at 100°–120° gained in weight 0·06 per cent.

* Loc. cit.

ART. VIII.—*The Composition of Nephelite*; by N. L. BOWEN.

THE composition of natural nephelite is a much discussed question. The earliest formula, expressing the composition as that of a simple orthosilicate $(Na,K)AlSiO_4$, is now generally recognized as incorrect since analyses always show somewhat higher silica than this formula requires. The formula $(NaK)_8Al_8Si_9O_{34}$, which is now commonly given in text-books of mineralogy, obviously attempts to account for this excess silica. Several analyses of excellent material have, however, been advanced by different investigators as evidence of the incorrectness of this formula. These analyses demonstrate that no definite formula can be assigned to nephelite since the excess of silica is variable in amount.

Moreover, the preparation of 'artificial soda-nephelite', $NaAlSiO_4$, by Doelter and others, showing crystallographic and optical properties essentially those of natural nephelite, demonstrated long since that this compound is the 'essential constituent' of natural nephelite.

The writer recently prepared this artificial soda-nephelite and determined its properties. The marked degree of correspondence with the natural mineral is set forth in the following table:

	Cryst'n	Opt. char.	ω	ε	G	habit
$NaAlSiO_4$ (artif.)	hex.	..	1·537	1·533	2·619	prism and base
Nephelite (nat.)	hex.	..	1·541	1·537	2·55–2·65	prism and base commonest

Several different investigators recognized this essential relation and sought to explain the composition of nephelite by imagining it to be a 'mixture' of $NaAlSiO_4$ with a potash molecule, either $KAlSi_3O_8$, or $K_2Al_2Si_3O_{10}$, or $K_4Al_4Si_5O_{18}$.

Each of these potash compounds has a silica ratio higher than that in an orthosilicate, and its presence in variable amount was intended to explain the excess of silica and its variable nature.

The preparation of soda nephelite by the writer, just mentioned, was accomplished by fusing together Na_2CO_3, Al_2O_3 and SiO_2 in the proper proportions. It was, however, found that a 'pure' product was obtained only with some difficulty on account of the partial volatilization of soda at high temperatures. When the 'impure' mixture first obtained was crystallized at a low temperature the microscope revealed nephelite

and corundum (Al_2O_3). But the loss of soda gave not only excess alumina but also excess silica, which, however, did not appear in any form, and therefore must have been held in solid solution in the nephelite. By mere chance, then, the explanation of the excess silica content of nephelite was hit upon. It is held in solid solution and is therefore variable, but no potash content is necessary.

This fact suggests that in natural nephelites potash and excess silica may be quite independent of each other. An examination of analyses proves that it is indeed so. This examination is readily accomplished with the aid of the following diagram, where composition is plotted on triangular coördinates with SiO_2, $K_2O.Al_2O_3$ and Na_2O, Al_2O_3 as apices. Only the significant segment of the plot is shown. CaO has been deducted from the analyses together with sufficient Al_2O_3 and SiO_2 to form $CaAl_2Si_2O_8$.

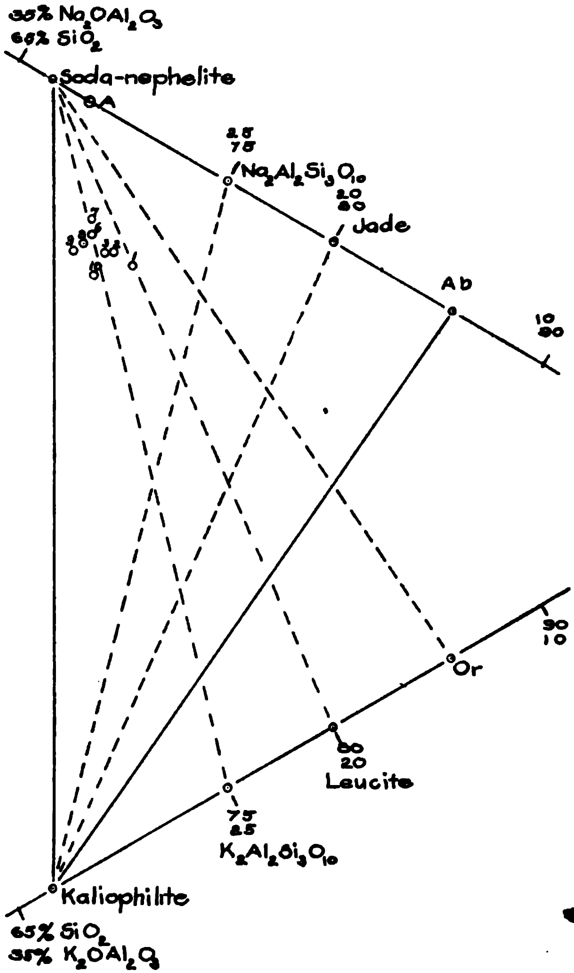
Each small numbered circle represents the composition of a nephelite. There is no apparent arrangement to the points. Obviously nephelites cannot be considered as a 'mixture' of soda nephelite with *any* potash compound, for all the points would then lie on the straight line joining these two compositions. Potash and silica vary quite independently.

An experimental study of the composition of nephelite was begun by the writer by making up mixtures in which there was excess silica (deliberate) but no excess alumina. The composition $Na_2O, Al_2O_3, 2.2SiO_2$ (A of diagram) was crystallized below 1200°, the temperature being kept low to prevent the formation of the high temperature form of nephelite (carnegieite). The product was a completely crystalline *perfectly homogeneous* mass with properties essentially those of the orthosilicate ($Na_2O, Al_2O_3, 2SiO_2$). The excess silica had simply disappeared in solid solution, as had been accidentally found before.

Mixtures with still greater excess of silica were experimented with in the attempt to find the limit of solubility and the excess phase after solubility was exceeded, but the increasing viscosity, and the necessity of crystallizing at a low temperature, prevented the formation of a determinable crystalline product. We have apparently a scanty amount of experimental results on which to base any conclusion, and yet when used in conjunction with facts known to be true of rocks, certain conclusions may be drawn.

It is more than probable that, had the attempts above mentioned been attended with success, albite ($Na_2O.Al_2O_3.6SiO_2$) would have been found as the excess phase. By analogy, then, with an ordinary aqueous solution of salt we would speak of our solution as one of albite in nephelite. The excess phase

FIG. 1.



1. Hintze, analysis 23.
2. Foote and Bradley, this Journal, xxxi, 25, 1911.
3, 7, 8 and 9. Morozewicz, Bull. Acad. Sci., Cracovie, 958, 1907.
6. Adams and Barlow, Mem. No. 6, Geol. Surv. Can., p. 236.
10. Hintze, analysis 34.

certainly would not have been silica, for the evidence from nature is that silica and nephelite do not occur together. The only other possibility is a compound of the type Na_2O $Al_2O_3 2+nSiO_2$, of which the most likely is albite, again from evidence in nature.

Foote and Bradley,* in a recent paper, express the opinion that the excess silica of natural nephelites must be regarded as present in solid solution. Their conclusion has the great advantage of being stated in modern phraseology, but there appears to be nothing in this view which is essentially different from and, therefore, refutes the older view of the presence in variable amount of some compound of higher silica content.

Foote and Bradley do, however, point out certain facts which suggest to the reader that the compound determining the excess silica is the soda compound albite and not a potash compound as the older views have insisted upon. One of these facts is that the nephelites are 'saturated' with silica when found in contact with the polysilicate albite, but Foote and Bradley themselves apparently consider that contact with sanidine should bring about a like result.

Still more recently Schaller,† seizing the truth in Foote and Bradley's discussion, has made the explicit statement that nephelites may be considered as composed of the three molecules $NaAlSiO_4$, $KAlSiO_4$ and $NaAlSi_3O_8$. The random position of the points on the diagram shows that the expression in terms of three components is a step in the right direction. Moreover the conclusion agrees with that indicated by experimental results.

Schaller supports his conclusion by testing it against actual analyses and finds a satisfactory concordance. But it should be pointed out that this test alone is not decisive. Had Schaller tried $KAlSi_3O_8$, or $KAlSi_2O_6$, or $Na_2Al_2Si_5O_{10}$, or $NaAlSi_2O_6$ instead of $NaAlSi_3O_8$, he would have found equally good concordance. This fact becomes obvious by reference to the diagram, since all the points representing compositions of nephelite fall within the triangles having for their common apices soda-nephelite and kaliophilite, and for the third apex the compounds mentioned respectively.

It so happens that all natural nephelites on whose analyses we may rely are doubtful to this extent, and at first sight it would appear that there is no reason for choosing any one as a third component rather than any other. The synthetic nephelite (A), however, leaves us to choose only between $Na_2Al_2Si_5O_{10}$, $NaAlSi_2O_6$ and $NaAlSi_3O_8$, of which the most likely is, as we have seen, albite. It is probable that there are natural nephelites whose composition would lie above the soda-nephelite, orthoclase line and for which albite would again be the only choice.‡

* This Journal, xxxi, 25, 1911. † Jour. Wash. Acad. Science, Sept. 19, 1911.

‡ Nephelite from Denise, Haute Loire, France (anal. 7, Dana's System), has a composition which would place it barely above the orthoclase, soda-nephelite line. The low summation in this analysis makes it probable, however, that no great significance can be attached to this fact.

For a great many nephelites, then, mere expression of composition in terms of three components may be accomplished in a number of different ways, but for a systematic method which we may hope to apply to all possible nephelites we must use the three molecules $NaAlSiO_4$, $KAlSiO_4$, and $NaAlSi_3O_8$, that Schaller has suggested. The artificial nephelite A enables one to come to this decision.

The ability to come to this definite decision also makes it possible to predict when nephelite may be expected to be 'saturated' with silica. The presence* of orthoclase in a rock may be considered as having a 'silicifying' effect on nephelite, but this effect would be limited, for the resultant composition could never pass above the orthoclase-soda-nephelite line. The artificial nephelite A shows that the composition may lie above that line. It is, therefore, only in the presence of albite itself that nephelites may be expected to be 'saturated' with silica.

It would appear that the presence of jadeite should bring about a like result, but this possibility may be disregarded in nature. The presence of the jadeite molecule in dilute solution in a hornblende or pyroxene would not have a comparable effect.

Indeed this remark applies equally well to albite itself. If the albite molecule were present as oligoclase or andesine it would, theoretically, not have an equal 'silicifying' effect on nephelite, for a nephelite saturated with albite would be in equilibrium only with a plagioclase saturated with albite and the only plagioclase saturated with albite is albite itself. On the other hand, a nephelite found associated with anorthoclase saturated with albite should itself be saturated with albite. The conditions necessary for the saturation of nephelite with albite are so unlikely to occur that it may be safely said that natural nephelites are probably never saturated.

Summary.

1. A diagram is given which shows that the composition of nephelites cannot be explained by assuming mutual solid solution of any two components. It is necessary to imagine solid solution among three components.

2. Mere expression of the composition of nephelites in terms of three components may be accomplished in a number of different ways.

3. From the results of synthetic work it becomes possible to decide upon one of these methods as the only one applica-

*By "presence" it is necessary to understand intimate association during the process of crystallization, not mere proximity.

ble to all possible nephelites. The decision falls upon the three components $NaAlSiO_4$, $KAlSiO_4$, and $NaAlSi_3O_8$, suggested by Schaller.

4. Conclusions are drawn as to when nephelite may be expected to be saturated with silica.

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ART. IX.—*Baddeleyite from Montana*; by AUSTIN F. ROGERS.

ON some corundum specimens from Montana, obtained from Ward's Natural Science Establishment, the writer noticed a black submetallic mineral. The nature of the mineral was not evident at sight, but it was soon identified by physical and chemical tests as baddeleyite or native zirconia, ZrO_2.

Baddeleyite is a very rare mineral, first described from the gem-bearing gravels of Ceylon by Fletcher.* It had also been found in decomposed jacupirangite (magnetite-pyroxenite) at Jacupiranga, São Paulo, Brazil, and was called brazilite by Hussak,† who later‡ withdrew his name in favor of baddeleyite. Hussak § has also described baddeleyite from Alnö, Sweden, where it occurs in magnetite-olivine segregations in nephelite-syenite.

The specimens obtained of Ward's were from Montana, but the exact locality was not stated. Similar specimens containing baddeleyite purchased from Mr. R. M. Wilke of Palo Alto, California, are from the property of the Bozeman Corundum Company, which according to Pratt‖ is fourteen miles southwest of Bozeman, Montana.

Occurrence.—The baddeleyite is an accessory constituent of a gneissoid corundum-syenite containing microcline-microperthite, biotite, and corundum, with subordinate amounts of muscovite, sillimanite, and zircon. It occurs in minute crystals and rounded blebs with a maximum size of about 3^{mm}. The baddeleyite is found in both the feldspar and the corundum, but is especially abundant on the surface of the corundum, and often adheres to the feldspar when the corundum crystals are broken out of the matrix.

* Mineralogical Magazine, vol. x, p. 148, 1893.
† Neues Jahrb. Min., 1892, vol. ii, p. 141.
‡ Min. Petr. Mitth., vol. xiv, p. 395, 1895.
§ Neues Jahrb. Min., 1898, vol. ii, p. 228.
‖ Bull. 269, U. S. G. S., p. 133, 1906.

Crystal Form.—The baddeleyite crystals are square-prismatic or tabular-prismatic in habit with only one well-defined zone with the forms {100}, {110}, and {010}. Eight crystals were measured on the reflection goniometer with indifferent results, the angle for (100 : 110) varying from about 44° to 46°. Finally, one crystal was found which gave the following measurements:

		Average	Calc.
100 : 110	44° 22′, 44° 25′, 44° 26′	44° 24′	44° 20′
110 : 010	45° 31′, 45° 35′, 45° 38′	45° 35′	45° 40′
100 : 010	89° 57′, 90° 0′, 90° 0′	89° 59′	90° 0′

The calculated angles established by Blake and Smith* are given in the last column.

For the angle (100 : 110) Fletcher gives 44° 0′ and Hussak, 44° 17½′. The terminal faces are obscure and rounded, but on one crystal faces of the form {$\bar{1}$11} were identified by the following measurements, (010 : $\bar{1}$11) = 63° 15′ (average of 62° 30′ and 64° 0′), the calculated value according to Blake and Smith being 64° 18′.

Physical Tests.—The cleavage seems to be in four directions, parallel to {100}, {110}, and {010}. The hardness is about 6½, for it scratches glass faintly and in turn is scratched by quartz. The luster is submetallic or metallic adamantine. The color is black, but in fragments it is translucent brownish red. The double refraction is strong, and the index of refraction is greater than that of methylene iodide. Some fragments show several sets of twinning lamellæ crossing each other. In thin-sections the baddeleyite appears as elongate crystals with almost parallel extinction and slight pleochroism, the greatest absorption being parallel to the length of the crystal.

Pyrognostic Tests.—The mineral is practically infusible when heated before the blowpipe, but examination with a high-power microscope shows a slight sprouting on the edges. In the oxygen-gas blowpipe† it is fairly easily fusible to a black globule. In the closed tube it is unaltered. When heated in the platinum forceps it glows with a brilliant light, which recalls the fact that zirconia is the principal constituent of the filament of the Nernst lamp.

Chemical Tests.—In fine powder the baddeleyite is insoluble in a sodium metaphosphate bead but is soluble in a borax bead giving a faint iron test. It is insoluble in aqua regia but is decomposed by strong sulphuric acid. The hydrochloric acid solution of the soda fusion turns turmeric paper orange, and since no green flame was obtained with boracic acid flux this

* Mineralogical Magazine, vol. xiv, p. 378, 1907.
† See Luquer, Sch. Mines Quart., vol. xxix, p. 179, 1908.

test is proof that zirconium is present. The acid solution of the soda fusion with ammonium hydroxide gave a white flocculent precipitate which is insoluble in KOH, but soluble in oxalic acid. The sulphuric acid solution with ammonium hydroxide gave a precipitate which glows when heated in platinum forceps before the blowpipe.

Baddeleyite as a Rock-forming Mineral.—Baddeleyite is one of the rare accessory minerals of igneous rocks. As far as known, it is confined to rocks low in silica, the jacupirangite of Brazil having only 38 per cent SiO_2, and the present corundum-syenite about 44 per cent. The deficiency in silica is probably the reason baddeleyite forms rather than zircon.

Identity with Baddeleyite.—From the presence of zirconium and the crystal habit one might call the mineral zircon, baddeleyite, or one of the zirconium-pyroxenes, låvenite, wöhlerite, or hiortdahlite. It is distinguished from zircon by luster, hardness, and cleavage; from altered zircon by the absence of water, and from the three zirconium pyroxenes mentioned by the solubility and fusibility. The angles in the prism zone [100 : 110 : 010] agree better with the baddeleyite angles than with the angles of the other minerals. The sum total of the characters undoubtedly identifies the mineral as baddeleyite.

Stanford University, California, September, 1911.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Uranium Hexafluoride.*—Since no hexavalent halogen compound of uranium has been previously prepared, the preparation of the fluoride UF_6 by Ruff and Heinzelmann is of considerable interest. It appears that a supposed previous preparation of this compound by Ditte was not founded on fact. Three methods were worked out for the preparation of the compound: 1. The action of fluorine upon uranium pentachloride; 2. The action of anhydrous hydrofluoric acid upon uranium pentachloride; 3. The action of fluorine upon metallic uranium or uranium carbide. According to the first two methods the product consisted of a mixture of two fluorides, according to the equations

$$2UCl_5 + 5F_2 = UF_4 + UF_6 + 5Cl_2 \text{ and}$$
$$2UCl_5 + 5H_2F_2 = UF_4 + UF_6 + 10HCl.$$

The higher fluoride, being very volatile, is easily separated from the other one, but when prepared according to the second method it was separated only with considerable difficulty from the excess of anhydrous hydrofluoric acid. The action of pure fluorine upon metallic uranium gave, as Moissan had shown, a product consisting chiefly of the tetrafluoride, but it was found that when a little chlorine was mixed with the fluorine, complete conversion into hexafluoride took place. The chlorine appears to act as a catalytic agent in this case.

Uranium hexafluoride is a very volatile, pale yellowish, crystalline solid which boils at 55° C. at atmospheric pressure. Its melting-point, 69·5° C., lies above its boiling-point, so that a pressure of about two atmospheres is required to melt it. The substance is extremely reactive; it is very sensitive toward moisture; it reacts with hydrogen even when cold; the chief product of its reduction appears to be uranium tetrafluoride. Its reaction with sulphur is particularly interesting, as it seems to give a new gaseous fluoride of sulphur.—*Zeitschr. anorgan. Chem.*, lxxii, 63.

H. L. W.

2. *The Atomic Weight of Extra-terrestrial Iron.*—Since, as far as is known, atomic weight determinations have always in the past been carried out with material of terrestrial origin, it seemed worth while to Baxter and Thorvaldson to make such a determination on an element of meteoric origin. Iron was selected as the subject of investigation, and for the purpose a piece of a 63 lb. meteoric iron found in 1903 near Cumpas, Mexico, was used. After an elaborate series of purification operations, ferrous bromide was prepared and analyzed according to a method that had been previously employed by the authors in connection with terrestrial iron. The results indicated no appreciable difference

between the atomic weights of the two kinds of iron, for the average of eight determinations on the meteoric material was 55·832, while the outcome of the results of the other work was 55·838.—*Jour. Amer. Chem. Soc.*, xxxiii, No. 3. H. L. W.

3. *The Compounds of Ammonia and Water.*—The question of the existence of the compound NH_4OH in solutions of NH_3 in water has attracted much attention in the past, but while the theory of the existence of the hydroxide has been a plausible one, it has been opposed by several investigators. SMITS and POSTMA have now shown from freezing-point determinations of mixtures of NH_3 and H_2O that the compounds $NH_3.H_2O$ and $2NH_3.H_2O$, corresponding to NH_4OH and $(NH_4)_2O$, certainly exist, and that these are the only compounds formed. They melt at about $-77°$ C. and $-78°$ C. respectively, or a little below the melting point of pure NH_3, while there are eutectics between the two compounds and between each of them and a constituent. The existence of these compounds, although it gives no proof of their chemical constitution, undoubtedly strengthens the hydroxyl and oxide theory, for it shows that NH_4 can be regarded as combining with water in the same way that an alkali metal does, for example, to produce KOH and K_2O. It may be added that Ruppert has obtained the same results by freezing-point determinations as those that have been mentioned, but published them somewhat later.—*Zeitschr. anorgan. Chem.*, lxxi, 250. H. L. W.

4. *The Quantitative Determination of Fluorine as Calcium Fluoride.*—The usual method for carrying out this determination, following Berzelius, is to precipitate the calcium fluoride together with calcium carbonate, and, after filtering and igniting the mixture, to dissolve out the calcium carbonate with dilute acetic acid and finally collect and weigh the fluoride. STARCK and THORIN have made a modification of this method, which consists in precipitating calcium fluoride in the presence of an exactly known amount of an oxalate in a solution containing about two cubic centimeters of free acetic acid. The amount of oxalate should be about the same as that of the fluoride. The precipitation is made in the hot solution by the addition of calcium chloride solution. The mixture, which filters as well as calcium oxalate alone, is collected on asbestos, dried at 210° C., and weighed. By deducting the known amount of calcium oxalate, the weight of fluoride is found. From the results obtained by the authors it appears that the method gives very satisfactory results, and it is evidently a great improvement upon the old method.—*Zeitschr. analyt. Chem.*, li, 14. H. L. W.

5. *The Volumetric Determination of Antimony in Alloys.*—Dr. G. S. JAMIESON of the Sheffield Laboratory has applied Andrews' iodate titration to this determination. The alloy, such as hard lead or solder, is dissolved in concentrated sulphuric acid by heating to boiling, the residue is treated with a mixture of equal volumes of strong hydrochloric acid and water, the lead sulphate is filtered off and washed with hydrochloric of the same

strength, and the filtrate is titrated directly in a bottle in the presence of a little chloroform with potassium iodate solution until the color of iodine, which is produced in the chloroform, at last disappears. The reaction in the presence of the strong hydrochloric acid proceeds according to the equation

$$2SbCl_3 + KIO_3 + 6HCl = 2SbCl_5 + KCl + ICl + 3H_2O.$$

Since tin, copper, and iron do not interfere with the method, it is convenient in many cases, and it appears to give very accurate results.—*Jour. Indust. and Eng. Chem.*, iii, No. 4. H. L. W.

6. *The Radio-activity of the Dürkheim Mineral Waters.*—Since it had been found by Ebler in an examination of the "Maxquelle" water of Dürkheim that a certain amount of radio-activity appeared to follow the alkali-metals, and since on this account it was suspected that a sixth alkali metal with radio-active properties might exist in this water, EBLER and FELLNER, in connection with an elaborate investigation of the radio-activity of these waters and their products, have made a further study of the question of the presence of a new alkali metal. The result, however, is disappointing from a chemical point of view, for they found that potassium salts prepared from the water of this spring showed no more radio-activity than ordinary potassium salts.—*Zeitschr. anorg. Chem.*, lxxii, 233. H. L. W.

7. *Bulletin of the Bureau of Standards.*—The third number of volume VII, recently issued, opens with a paper by L. W. AUSTIN, giving in detail the results of *Some quantitative experiments in long-distance radiotelegraphy.* These tests were carried on two years since under the auspices of the Navy Department between two cruisers and the wireless station at Brant Rock. Measurements were made up to a distance of one thousand miles, their chief object being the determination of the law governing variations of strength of signal with the distance. The results arrived at, briefly stated, are as follows:

"(*a*) Over salt water the electrical waves decrease in intensity in proportion to the distance as found by Duddell and Taylor. In addition they are subject to an absorption which varies with the wave length and which may be expressed mathematically by the term e^{-Ad}. The complete expression for the received current is then

$$I_R = \frac{K}{d} e^{-Ad}.$$

This is true in general for day transmission. The absorption at night is entirely irregular, varying from zero to the day value, but is on an average much less during the winter than in summer. Variations also appear to occur during the daytime, but these are probably in general small.

"(*b*) The received antenna currents between two stations with salt water between are proportional to the product of the heights of the sending and receiving antennas and inversely proportional

to the wave length, provided the antenna resistances remain constant. These experiments were carried on with flat-top antenna heights of from 30 to 80 feet and wave lengths from approximately 1500 to 4000 meters.

"(c) Taking account of the influence of antenna height and wave length, the above equation may be extended and a general day transmission formula written as follows:

$$I_R = 4 \cdot 25 \frac{I_S h_1 h_2}{\lambda d} e^{-\frac{0 \cdot 0015 d}{\sqrt{\lambda}}}$$

where the currents are given in amperes and all lengths in kilometers. This formula has been tested for sending currents from 7 to 30 amperes, antenna heights 37 to 130 feet, wave lengths from 300 to 3750 meters, and distances up to 1000 nautical miles.

"In regard to the value of the day absorption it is only possible to say that the above expression is satisfied within the limits of error of the observations. It is quite possible that when observations are made at distances of 2000 to 3000 miles, the value of the absorption coefficient will have to be corrected by 10 or even 20 per cent, as this amount of error could exist without discovery at the distances covered in these experiments. It is also possible that the square-root law relating the absorption with the wave length is only an approximation."

The other papers in the same number include one by C. E. Waters on the behavior of high-boiling mineral oils on heating in the air; another by J. R. Cain on determination of vanadium in vanadium and chrome-vanadium steels; by E. Buckingham and J. H. Dellinger on the constant C_2 of Planck's equation for the intensity of radiation; by T. T. Fitch and C. J. Huber on American voltmeters and ammeters; by P. G. Agnew on the current transformer; and by H. S. Carhart on thermodynamics of concentration cells.

Circular No. 24 (pp. 41) gives a summary of the published work of the Bureau of Standards, which is remarkable in extent, considering the short time since the Bureau was established. Seven volumes of the Bulletin have appeared, the first in 1904–5; in all 174 papers are enumerated, some of these now in press; these are here classified and their contents briefly indicated. A series of thirty-one circulars of the Bureau is also enumerated; these give the regulations under which the tests and comparisons of the Bureau are made, with a general statement as to its work.

8. *Annual Tables of Constants and Numerical Data, Chemical, Physical and Technological.*—The first volume of the Annual Tables of Constants and Numerical Data, Chemical, Physical and Technological, compiled and published by an international commission, appointed by the 7th International Congress of Applied Chemistry (see Science, August 4, 1911, p. 158), is now open to subscription. Subscription blanks, the terms of subscription and descriptive leaflets may be obtained from any one

of the three American Commissioners: Dr. G. N. Lewis, the Massachusetts Institute of Technology, Boston, Mass.; Professor G. F. Hull, Dartmouth College, Hanover, N. H., and Professor J. Stieglitz, the University of Chicago, Chicago, Ill. After Jan. 15th, 1912 the price of the volume is likely to be increased.

9. *The Sun;* by CHARLES G. ABBOT. Pp. xv, 448; 26 plates, 72 figures. New York, 1911 (D. Appleton & Company).—A notable work which every student of physics and of astronomy will find of absorbing interest. It is the first considerable book bearing its title since that of Professor C. A. Young, so usefully and widely known, published just thirty years earlier; and it is pleasing to find that its frontispiece, like that of its predecessor, is a reproduction of S. P. Langley's famous drawing of a typical sun-spot, unfortunately somewhat marred, however, by a partial filling of the nucleus of the spot. This is to be regretted because too many contemporary readers will get an inadequate impression of the merit of the wonderful original drawing.

It is impossible in a brief review to do more than indicate in the most cursory manner some of the important advances in astrophysics which are here admirably set forth. The first five chapters cover much the same ground as Young's treatise, with amplified and modernized discussion of methods for determining the radiation of the sun, together with excellent reproductions of some of the most significant spectroheliograms from the Mt. Wilson observatory. Of the remaining five chapters, the seventh, —The sun as the earth's source of heat—and the tenth—The sun among the stars—perhaps contain the greater number of modern additions to knowledge which would interest a philosophical reader; but the chapter giving a succinct history of the efforts of inventors to utilize solar energy is interesting and valuable. The excellence of the reproductions of recent photographs of nebulæ should not pass unnoted. C. S. H.

10. *Physical Optics;* by ROBERT W. WOOD. Pp. xvi, 705; 2 plates, 399 figures. New York, 1911 (The Macmillan Company).—This is a second and enlarged edition of the work reviewed at length in this Journal (see vol. xxii, p. 193, 1906). The additions in this volume are material both in quantity and in importance; of these the last chapter, on the principle of relativity, may be especially named on account of its interest. C. S. H.

11. *Illumination, its Distribution and Measurement;* by ALEXANDER PELHAM TROTTER. Pp. xvii, 292; 209 figures. London, 1911 (Macmillan & Co.)—The frontispiece is a reproduction of a portrait by Perroneau of Pierre Bouguer, "the father of photometry," to the memory of whom this volume is dedicated. This book is an expansion of a paper which, on May 10, 1892, was read before the Institution of Civil Engineers and which was first published in volume cx of the Proceedings of the Institution. The paper was subsequently rewritten and it then appeared in The Illuminating Engineer.

The subject matter is divided into three parts. The first deals with the primary and derived units of light, with the theory of

the distribution of illumination, and with the application of that theory to the spacing and height of lamps. The second part describes instruments and methods employed for measuring light and illumination. The last part gives a few practical examples of the measurement of illumination. The book is intended for "practical engineers", so that graphical methods are employed throughout, to the exclusion of equations and formulæ. "The calculated curves and diagrams have been drawn on a large scale and most of them are accurate within the thickness of the line." The appendix comprises five tables of numbers, useful in photometric calculations, and also an explanation of the "Refraction Goniometer." Then follows a fairly complete bibliography of the subject of illumination. On the whole, the book is of a very elementary character. H. S. U.

12. *Kometen und Elektronen;* von AUGUSTO RIGHI. Deutsch von Max Iklé. Pp. 64. Leipzig, 1911 (Akademische Verlagsgesellschaft M. B. H.).—This is an excellent popular exposition of the modern theory which attributes the phenomena of comets' tails to the action of radiation pressure upon the electrons and ions of which the tail is supposed to be constituted. An interesting feature of the pamphlet is the collection, in the last chapter, of the results of observations on the earth's atmosphere during the passage of the earth through the tail of Halley's comet. Though the effects were much less marked than had been expected, and are perhaps in many cases doubtful, yet there are a number of observations recorded which are suggestive and interesting.

H. A. B.

II. GEOLOGY AND MINERALOGY.

1. *Publications of the Geological Survey of the United States;* GEORGE OTIS SMITH, Director.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from vol. xxxii, pp. 320, 321):

MONOGRAPH.—The Geology of the Lake Superior Region; by CHARLES R. VAN HISE and CHARLES K. LEITH. Pp. 641; 49 plates, 76 figures.

PROFESSIONAL PAPER No. 73.—The Tertiary Gravels of the Sierra Nevada of California; by WALDEMAR LINDGREN. Pp. 226; 28 plates, 16 figures.

MINERAL RESOURCES.—Advance chapters in the production in 1910 of Platinum and allied metals, of Petroleum, of Magnesite, of the Stone Industry, etc.

BULLETINS.—No. 466. Retracement of the Boundary Line between Idaho and Washington from the junction of Snake and Clearwater Rivers northward to the International Boundary. R. B. MARSHALL, Chief Geographer. Pp. 39; 7 plates, 1 figure.

No. 467. Geology and Mineral Resources of parts of the Alaska Peninsula; by WALLACE W. ATWOOD. Pp. 137; 14 plates, 18 figures.

No. 474. Coals of the State of Washington ; by E. Eggleston Smith. Pp. 206 ; 8 plates.

No. 478. Geology and Ore Deposits near Lake City, Colorado ; by John D. Irving and Howland Bancroft. Pp. 128 ; 8 plates, 33 figures.

No. 483. Economic Geology of Richmond, Virginia, and Vicinity ; by N. H. Darton. Pp. 48 ; 10 plates, 1 figure.

No. 484. The Granites of Connecticut ; by T. Nelson Dale and Herbert E. Gregory. Prepared in coöperation with the Geological and Natural History Survey of Connecticut. Pp. 137; 7 plates, 12 figures.

Nos. 486, 487, 488, 489. Results of Spirit Leveling ; R. B. Marshall, Chief Geographer. No. 486. In Colorado, 1896–1910. Pp. 107, 1 plate. No. 487. In Idaho, 1896–1909. Pp. 46, 1 plate. No. 488. In Nevada, 1897–1909. Pp. 28, 1 plate. No. 489. In Utah, 1897–1910. Pp. 38, 1 plate.

No. 490. Mineralogical Notes. Series I ; by Waldemar T. Schaller. Pp. 109 ; 14 figures.

No. 491. The Data of Geochemistry. Second Edition ; by Frank W. Clarke. Pp. 782.

No. 495. Bibliography of North American Geology for 1910, with subject index ; by John M. Nickles. Pp. 179.

Water Supply Papers—No. 239. The quality of the Surface Waters of Illinois ; by W. D. Collins. Pp. 94 ; 3 plates.

Nos. 261, 269, 271, 272, 288. Surface Water Supply of the United States, 1909. Prepared under the direction of M. O. Leighton. No. 261, Part I. North Atlantic Coast ; by H. K. Barrows, C. C. Covert, R. H. Bolster. Pp. 309 ; 5 plates, 1 figure. No. 269. Part IX, Colorado River Basin ; by W. B. Freeman and R. H. Bolster. Pp. 247 ; 9 plates, 1 figure. No. 271. Part XI, California ; by W. B. Clapp and F. F. Henshaw. Pp. 256 ; 6 plates, 1 figure. No. 272. Part XII, North Pacific Coast ; by J. C. Stevens, E. C. LaRue and F. F. Henshaw. Pp. 521 ; 8 plates. No. 288. Part VIII, Western Gulf of Mexico ; by W. B. Freeman and J. G. Mathers. Pp. 149 ; 3 plates, 1 figure.

No. 278. Water Resources of Antelope Valley, California ; by Harry R. Johnson. Pp. 92 ; 7 plates, 11 figures.

2. *U. S. Bureau of Mines*, Joseph A. Holmes, Director.—The work of the Bureau of Mines, established in 1910, has been carried actively forward. The Bulletins recently issued include the following:

No. 7. Essential Factors in the Formation of Producer Gas ; by J. K. Clement, L. H. Adams, and C. N. Haskins. Pp. 58 ; 16 figures.

No. 8. The Flow of Heat through Furnace Walls ; by W. T. Ray and Henry Kreisinger. Pp. 32, 19 figures.

No. 12. Apparatus and Methods for the Sampling and Analysis of Furnace Gases ; by J. C. W. Frazer and E. J. Hoffman. Pp. 122 ; 6 figures.

No. 13. Résumé of Producer-Gas Investigations. Oct. 1, 1904–June 30, 1910; by R. H. FERNALD and C. D. SMITH. Pp. 393; 12 plates, 250 figures.

No. 14. Briquetting Tests of Lignite at Pittsburg, Pa., 1908–9, with a chapter on Sulphite-Pitch Binder; by CHARLES L. WRIGHT. Pp. 64; 11 plates, 4 figures.

No. 15. Physical and Chemical Properties of the Petroleums of the San Joaquin valley, Cal.; by I. C. ALLEN and W. A. JACOBS. With a chapter on Analyses of Natural Gas of Southern California; by G. A. BURRELL.

Several Technical Papers have also been issued, and further the following Miners' Circulars: No. 3 on Coal-dust Explosives; by G. S. RICE; No. 4, on Use and Care of Mine-rescue breathing Apparatus; by JAMES W. PAUL.

No. 5. Electrical Accidents in Mines; their Prevention and Treatment; by H. H. CLARK. 1911.

3. *Geological Survey of New Jersey.* HENRY B. KÜMMEL, State Geologist. *Iron Mines and Mining in New Jersey;* by WILLIAM S. BAYLEY. Vol. VII of the Final Report Series of the State Geologist. Pp. xv, 512; 13 plates, 31 figures, 2 pocket maps. Trenton, N. J., 1910.—A large amount of data relating to the iron ores of New Jersey, distributed through some forty volumes of the Annual Reports, have been brought together in the present volume, which is thus a thorough presentation of all that is important in regard to the iron-mining industry of the state. Although the work is essentially a compilation, the thoroughness with which the facts have been assembled will be appreciated from the statement that every mine hole has been revisited and every mine dump carefully examined. As is well known, the iron ores of New Jersey are chiefly magnetite, which occurs in the pre-Cambrian rocks of the state. The larger part of the volume is devoted, consequently, to the general statement of the occurrences and origin of the magnetite, followed by detailed facts in regard to individual mines. An account is also given of the bog ores and of limonite, which in former years were extensively mined, although of relatively small importance at the present time. The occurrences of hematite are limited in number and have never been extensively mined.

4. *Geological Survey of Alabama;* EUGENE ALLEN SMITH, State Geologist.—The following Bulletins have recently appeared:

No. 10. Reconnoissance Report on the Fayette Gas Field, Alabama; by M. J. MUNN. Pp. 66; 2 plates, 2 maps. Prepared in coöperation with the U. S. Geological Survey.

No. 11. Roads and Road Materials of Alabama; by WILLIAM F. PROUTY. Pp. 148; 20 plates, 2 figures.

5. *The Data of Geochemistry, Second Edition;* by FRANK WIGGLESWORTH CLARKE. Pp. 782 (U. S. Geol. Surv., Bull. 491).—The first edition of this invaluable work was published in 1908 and noticed in this Journal at that time (see vol. xxv, p. 458). In its revised and enlarged form it now appears with sixty-six addi-

tional pages. The labor of the author in thus bringing the volume up to date will be appreciated by a large number of workers in science.

6. *American Permian Vertebrates;* by SAMUEL W. WILLISTON. Pp. 145; 39 plates and many text illustrations. University of Chicago Press, 1911.—In this book Professor Williston brings together "a series of monographic studies, together with briefer notes and descriptions, of new or little-known amphibians and reptiles from the Permian deposits of Texas and New Mexico." He does not think it worth while as yet to "enter extensively into many suggested morphological and taxonomical discussions." We need "more facts, many more facts, and I have little faith in any system of classification based upon our present knowledge of these older land vertebrates." However, certain morphological problems are set forth and what the author regards as "the legitimate conclusions regarding the immediate relationships of the forms under discussion" are given.

The two wonderful graveyards of Permian vertebrates discovered by Professor Williston in Texas are described under the captions Cacops Bone-Bed and Craddock Bone-Bed, while something is also added of the Permian locality of New Mexico.

Many of the animals described in this volume are based on omplete or nearly complete skeletons, and herein lies the greatest value of the book. Then, too, all of the illustrations were made by the author. The orders Temnospondyli, Cotylosauria and Theromorpha are defined, along with eight of their families and seventeen species. C. S.

7. *Analyses of Stone Meteorites*; by O. C. FARRINGTON. Field Museum of Natural History. Publication 151. Geol. Series, vol. iii, No. 9, pp. 195–226.—The author a few years since published a compilation of the analyses of iron meteorites, and he has now accomplished a similar work for stone meteorites. Some one hundred and twenty-five analyses are included, and to them the principles of the Quantitative Classification for terrestrial rocks, with some necessary modifications, have been carefully applied. It is interesting to quote here the general average arrived at for the composition of stone meteorites, which agrees pretty closely with that earlier obtained by Merrill.

AVERAGE COMPOSITION OF STONE METEORITES.

SiO_2	39·12
Al_2O_3	2·62
Fe_2O_3	·38
Cr_2O_3	·41
FeO	16·13
MnO	·18
NiO	·21
MgO	22·42
CaO	2·31

Na_2O	·81
K_2O	·20
H_2O	·20
Fe	11·46
Ni	1·15
Co	·05
S	1·98
P	·04
P_2O_5	·03
C	·06
Ni, Mn, Cu, Sn	·02
TiO_2	·02
SnO_2	·02
	99·82

The following table also gives the average composition of iron meteorites compiled from 318 analyses. Further, the proportion

AVERAGE COMPOSITION OF IRON METEORITES.

Fe	90·85
Ni	8·52
Co	·59
P	·17
S	·04
C	·03
Cu	·02
Cr	·01
	100·23

of elements present in meteorites of both classes has been computed as given below, following out the suggestion of the author that this may very probably correspond with the proportions of the elements in the earth as a whole.

PROPORTION OF ELEMENTS IN THE EARTH AS A WHOLE AS DEDUCED FROM METEORITES.

Iron	72·06
Oxygen	10·10
Nickel	6·50
Silicon	5·20
Magnesium	3·80
Sulphur	·49
Calcium	·46
Cobalt	·44
Aluminium	·39
Sodium	·17
Phosphorus	·14
Chromium	·09
Potassium	·04
Carbon	·04
Manganese	·03
Other elements	·05
	100·00

He closes with the following paragraph :

The large proportion of iron in the constitution of the earth indicated by meteorites is in accord with the earth's density, rigidity, and magnetic proportions. Assuming the density of the rocks of the earth's crust to be 2·8, which may be too high, and combining with it metal of the density of 7·8, which is an average of the density of iron meteorites, it will be found that 77·58 per cent of metal will be required to obtain a density of 5·57, that of the earth as a whole. This is very nearly that of the sum of the metals in the above result after eliminating the proportions present as oxides. Such a proportion of iron would seem to be in accord, as has been stated, with the earth's rigidity and magnetic properties.

8. *The Mineralogy of Pennsylvania. Part Two. Chemical Analyses;* JOHN EYERMAN. Pp. 25. Easton, Pa., 1911.—The first part of these contributions was issued more than twenty years ago, and was noticed in the Journal at that time (see vol. xxxvii, 501, 1889). The present part contains chemical analyses of many species, and also records of new localities. Unfortunately the results of a large number of analyses made were destroyed by fire sometime since, but those here given are numerous and will be of value to mineralogists.

9. *Praktikum der experimentellen Mineralogie;* von Dr. ERNST SOMMERFELDT. Pp. xi, 192, 61 text figures, 1 plate. Berlin, 1911 (Gebrüder Borntraeger).—This is a convenient little book for the student who must instruct himself in practical mineralogy. It takes up briefly the successive parts of the subject, and on the chemical side is much fuller than the elementary textbooks usually are ; there is, for example, a chapter giving the fundamental principles underlying the phenomena of fusion and crystallization of substances under different conditions.

10. *Uraninite from German East Africa.*—The uraninite locality in the mica quarries of the Uruguru Mts., German East Africa, has recently afforded, as announced by R. Brauns, a large cubic crystal weighing 154 grams and measuring 3·5 × 2·5 × 2 centimeters. The specific gravity found was 7·7 ; that of the pure nucleus being 8·84 and of the crust 4·82. The locality was first described by W. Marckwald in 1906.—*Centralblatt Min.*, 1906, p. 761 ; 1911, p. 689.

11. *Production of Platinum in 1910.*—The increased demand for platinum in recent years, chiefly caused by its use in jewelry, and the resulting rise in price reaching $45 per ounce in September, 1911, gives especial interest to the advanced chapter by W. Lindgren on its production in 1910 from Mineral Resources of the United States. Unfortunately the increased demand has thus far brought no considerable increase in quantity. In this country crude platinum is obtained in small quantities from the placer mines of California and Oregon. The amount for 1910 was 337 and 53 ounces respectively. The production of crude platinum in troy ounces for the world at large for 1909 and 1910 is given in the following table.

	1909	1910
Russia	* 264,000	* 275,000
Canada	* 30	* 30
New South Wales	440	332
Columbia	* 6,000	10,000
United States, domestic crude	672	390
United States, from foreign and domestic matte and bullion	† 600	† 1,000
Borneo and Sumatra	* 500	* 200
	272,242	286,952

* Estimated. † Refined.

12. *Les Syenites Nepheliniques de l'Archipel de Los et leur Mineraux;* par A. Lacroix. Nouv. Arch. d. Mus. (5), iii, 1–132, pl. i–x. 1911.—It is indeed remarkable what a variety of types of rocks, mineralogical and structural, are afforded by the highly alkalic magmas. This observation is, in fact, almost trite, since nearly every few months there occurs some new example of it. The variety of minerals which may be present seems almost endless, and new ones constantly present themselves. These features are strikingly illustrated in Lacroix's last work on rocks of this family. The Los Islands are a group of three small islands close to the shore of French Guinea on the west coast of Africa. The existence of nephelite rocks in them was first made known in 1887 by Gürich, and Lacroix himself has published at several times preliminary notes on material brought from them. The present work is based on rather full collections made by several persons, and the information obtained permits the publication of a preliminary geologic sketch-map.

In addition to types of nephelite-syenites with ægirite and with alkalic amphibole the usual members of this clan are well represented; pulaskite, aplites with nephelite, syenites with lovenite, with hiortdahlite, with hauyn and with sodalite, tinguaites, and micro-monzonites, micro-essexites, micro-theralites, micro-shonkinites, camptonites and monchiquites are among the varieties present. Of especial interest is an occurrence of lujavrite in the midst of an area of pegmatite and of tawite (rock composed essentially of sodalite) recalling those of Greenland and Kola. A special type of lamprophyre, consisting of phenocrysts of andesine-labradorite, augite, apatite and titanomagnetite in a groundmass of andesine laths, biotite, titanite, and a little barkevikite and augite, which is neither a camptonite nor a kersantite, is called (not very happily to English ears) *topsailite*, from the name of the cape upon which the dike occurs. The chemical composition of this is as follows:

SiO_2,	Al_2O_3,	Fe_2O_3,	FeO,	MgO,	CaO,	Na_2O,	K_2O,	H_2O,	P_2O_5,	TiO_2
48·88	20·56	3·34	5·29	3·09	8·34	4·75	2·56	0·32	0·73	1·69=99·55

In the quantitative classification this is andose.

An interesting new mineral is sodium fluoride, which is called *villiaumite* (after Villiaume, the collector of the material), which occurs as one of the accessory constituents of the nephelite-syenite in several places in the form of violet or carmine-red grains. It is thought to be tetragonal; cleavages good 001 and 100; double refraction almost wanting, but is negative; index 1·328, less than that of water and smallest of known minerals; hardness 2–2·5; specific gravity 2·8. It has in thick sections pleochroism in the red variety. Is soluble in water.

The name of *losite* is given to a mineral whose properties are much like those of cancrinite, from which it differs, however, in several particulars, notably in lesser birefringence (·001–·012). Material could not be obtained for chemical investigation.

In addition to those mentioned, other interesting rare minerals found in these rocks are astrophyllite, rinkite, wöhlerite, eudialyte, catapleiite and pyrochlore.

Lacroix contrasts these rocks with those which constitute the adjoining coast, and which he describes as hypersthene granites (charnockite) and norite of the Ivory Coast, and gabbros and peridotites (wehrlite and dunite) of French Guinea. He finds that the analyses of the wehrlite and dunite prove them to fall in unnamed sections of the Quantitative Classification and he proposes for the former the designation *kakoulimose* (V, 1 (4), 1 (1), 2) and for the latter *guinéose* (V, 1 (5), 1 (1), 2).

The memoir contains a considerable number of analyses and is an important addition to our knowledge of the alkalic rocks. The fine plates show many interesting petrographic details. As no associated rocks, or strata, are known, the occurrences add nothing at present to our knowledge of the origin of such rocks, or to their geological age. L. V. P.

13. *Potash in the United States.*—The efforts being made to find a supply of potash in this country are detailed in an advance chapter by Hoyt S. Gale from the Contributions to Economic Geology. The work of Gilbert and Russell showed reasonable ground for the theory that concentrated beds of workable and commercially valuable salines may exist in the strata underlying the Great Basin deserts. Accordingly work at Fallon, in northern Nevada, was begun on October 6; on December 1 the well was 360 feet deep, and it is expected that drilling will be continued until a depth of at least 1,000 feet is reached. The author adds that "There is a good possibility that deposits of the Stassfurt type exist in the United States. Probably the only feasible method of exploring for such deposits is by drilling. The work at Fallon is now fairly started but is no more than a beginning on the project as a whole. It is well that the work should proceed cautiously at the start, as little is to be gained by hasty or ill-considered expenditure. Experience gained in the preliminary tests now under way should help to make each succeeding test more effectual. It is to be hoped that the project already undertaken will be carried to a satisfactory conclusion, and if this is to

be accomplished the work will have to be continued beyond the limits of the present appropriation. . . . The German discovery was made only after five years' work in a single shaft, and it would be hardly reasonable to expect immediate results in this country."

III. Miscellaneous Scientific Intelligence.

1. *Heredity in Relation to Evolution and Animal Breeding;* by William E. Castle. Pp. xii, 184, with many illustrations and diagrams. New York, 1911. (D. Appleton and Company.) —At a time like the present, when new discoveries in genetics are being made with such bewildering rapidity that it is almost impossible for the layman to realize the significance of the vast amount of accumulated data, it is important that a popular summary should be made occasionally, showing exactly what the actual advance in the science has been. No one in this country is better fitted by his experience in experimental breeding to discuss this matter than the author of this attractive little book, and he has succeeded admirably, with the aid of well-chosen illustrations and diagrams, in his attempt to present in a manner intelligible to the general reader the essential principles involved in the hereditary processes, and their significance in the breeding and improvement of races of plants and animals. The work is naturally based upon the applications of Mendel's law of heredity to the inheritance and evolution of characters, including the effects of inbreeding and the inheritance of sex. W. R. C.

2. *Animal Intelligence: Experimental Studies;* by Edward L. Thorndike. Pp. viii, 297. New York, 1911 (The Macmillan Company).—The Publication of Thorndike's studies on the Associative Processes in Animals (in the Phychological Review, 1898) may be said to have inaugurated in this country the study of animal intelligence and behavior by exact experimental methods. This paper was followed by others on the Instinctive Reactions of Young Chicks, the Phychology of Fishes, and the Mental Life of the Monkeys. These studies have been reprinted in this book, and to them have been added essays on the Laws and Hypotheses of Behavior and the Evolution of the Human Intellect. Not only will the collection of these papers and their publication in accessible form be appreciated by all students of animal behavior, but the articles are in themselves well adapted to form the chapters of a book of general interest. W. R. C.

3. *The Parasitic Amœbæ of Man;* by Charles F. Craig. Published with the authority of the Surgeon General of the United States Army. Pp. x, 253; 30 figures. Philadelphia, 1911 (J. B. Lippincott Company).—For a number of years it has been generally known that some of the more serious human

diseases, such as certain forms of dysentery, are due to the presence of parasitic amœbæ. This book describes in detail all the kinds of amœbæ found in the human body and discusses the life cycle and reactions of each species, with emphasis on its distribution in the body and its relation, if any, to disease. W. R. C.

4. *The Inland Lakes of Wisconsin: The Dissolved Gases of the Water and their Biological Significance;* by EDWARD A. BIRGE and CHANCEY JUDAY. Bull. xxii, pp. xx, 259. Wisconsin Geological and Natural History Survey, 1911.—This book discusses the distribution of gases in the water of certain lakes, with the variation at different depths and over a considerable period of time, and the correlation between the presence of the various gases and the abundance of organisms. W. R. C.

5. *A Laboratory Guide in Bacteriology;* by PAUL G. HEINEMAN. 2d ed. Pp. 193. Chicago (The University of Chicago Press).—The book is well suited for an elementary guide in general bacteriological technic. Its scope is indicated by the following divisions; bacteriological technic, general bacteriology, important pathogenic bacteria, the bacteriological examination of water and sewage, of milk and of soil, and yeasts, moulds, etc. L. F. R.

6. *Annual Report of the Board of Regents of the Smithsonian Institution, showing the Operations, Expenditures and Condition of the Institution for the Year ending June 30, 1910.* Pp. vii, 688, with numerous illustrations. Washington, 1911.—The annual volume of the Smithsonian Institution opens with the report of the Secretary, which was noticed in this Journal at the time of its advance publication (see vol. xxxi, p. 155). The general Appendix which follows (pp. 111–688), in accordance with the plan followed since 1889, contains a selection of papers covering a wide range of topics, but all of interest to the general public both in matter and in method of presentation. One of these is a republished paper by Octave Chanute giving a fully illustrated account of recent progress in aviation. There are also papers on the atmosphere of the sun by H. Deslandres; on the future habitability of the earth by T. C. Chamberlin; on methods of testing explosives by C. E. Munroe. In continuation of a series of earlier papers, F. H. Newell discusses the progress made in the reclamation of arid lands in the western part of the United States; other papers of more or less distinctly original character are by C. M. Clark on the development of electric power from the Mississippi River; on a review of current research in isostasy by Bailey Willis, and on forest preservation by Henry S. Graves.

7. *Twenty-seventh Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1905–1906.* Pp. 672; 132 figures, one map. Washington, 1911.—This volume contains the administrative report of the Chief of the Bureau, W. H. HOLMES (pp. 1–14) and accompanying this (pp. 17–672) an exhaustive monograph on the Omaha tribe of the Sioux nation. This has been prepared by Miss ALICE C.

FLETCHER, who, for many years, has been carrying on these studies under relations which allowed of intimate knowledge of the Indians and their life. As joint author, a member of the tribe, Francis La Flesche, has been associated. The ceremonies and customs of the tribe are given with much fulness, and thus we gain a representation of the people as they existed during the earlier part of the last century. The value of the work is much increased from the fact that it is based upon the original material gathered directly from the natives themselves.

The Bureau has also published the following Bulletins:

No. 44. Indian Languages of Mexico and Central America; by CYRUS THOMAS assisted by JOHN R. SWANTON. Pp. vii, 108, with Linguistic map of Mexico and Central America.

No. 51. Antiquities of the Mesa Verde National Park: Cliff Palace; by JESSE W. FEWKES. Pp. 82; 35 plates, 4 figures.

8. *Appleton's Scientific Primers.* Edited by J. REYNOLDS GREEN.—This series of science primers includes the following: Chemistry by W. A. TILDEN; Biology by R. J. HARVEY GIBSON; Botany by J. REYNOLDS GREEN; Geology by J. W. GREGORY. These little volumes have been prepared for a reader having no previous knowledge of the various subjects, and although very brief and elementary in character, the effort has been to present the subjects from the modern standpoint. It is suggested that the Chemistry Primer should be taken up first, to be followed by that on Biology, and then the more special subjects of Botany and Geology.

OBITUARY.

Sir JOSEPH DALTON HOOKER, the eminent English botanist, died on December 11 in the ninety-fifth year of his age. Born in 1817, he accompanied, when only twenty-one, the expedition of Sir James Ross to the Antarctic as assistant-surgeon on board the Erebus. In 1847 he traveled extensively in the Himalayas investigating the flora of the region, and later he made other botanical expeditions to the East. In 1855 he was made assistant director of the Kew Gardens and ten years later he became Director, succeeding in that position his father, Sir William Hooker. His contributions to botany, in the development of the Kew Gardens as well as in the results of his original discoveries and investigations, have given him a rare position in English science.

Professor GEORGE DAVISON, for thirty years head of the United State Coast and Geodetic Survey of the Pacific coast and Professor emeritus in the University of California, died early in December at the age of eighty-six years.

Dr. WILLIAM SUTHERLAND, well known through his work in molecular physics, died at Melbourne on October 4 at the age of fifty-two years.

Professor GIORGIO SPEZIA, the Italian geologist, died at Turin on November 10.

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FOURTH SERIES

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THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. X.—*A Study of Some American Fossil Cycads.—Part VI.* On the Smaller Flower-Buds of Cycadeoidea*; by G. R. Wieland.

[Preliminary Notes published by permission of the Carnegie Institution of Washington.]

In continuing the studies of silicified cycads begun in 1898 one of the most pleasing results obtained has been the discovery that some of the large and fine trunks at first thought to bear rather young fructifications are full grown plants, their flower-buds being in reality of quite mature pygmic type.

Of these trunks, which evidently fall into several distinct specific series, the one to which most study has been devoted is No. 3 of the Yale collections. Originally referred by number only together with various other Yale cycads and one U. S. National Museum specimen to *Cycadeoidea dacotensis*,† this handsome columnar trunk or possibly branch is, as it now proves, in nowise to be confused with younger examples of that species. Instead it clearly agrees specifically with those notably beautiful branched trunks figured under the name *Cycadeoidea Marshiana* on Plate VI, figures 7 and 9, and on Plates VII, VIII and IX, figure 1, of my American Fossil Cycads (Structure).

Conversely, the superb branching trunk figured by Ward‡ and signalized as "the type" of *Cycadeoidea Marshiana* has not been found to present any real differences from *Cycadeoidea*

* Parts I–III of these studies of American fossil cycads appeared serially in this Journal for March–May, 1899, Part IV in June, 1901, and Part V in August, 1911. See also December, 1904—The Proembryo of the Bennettiteæ, February, 1908—Historic Fossil Cycads, and December, 1911—On the Williamsonian Tribe.

† Ward, Lester F., Cretaceous formations of the Black Hills. Washington, 1899.

‡ Loc. cit., Plates CI–CIII.

dacotensis Macbride. In fact several cylindrical cores drilled from this latter trunk contain bisporangiate strobili well enough conserved to make it certain that they have the same structure as those cut from such typical specimens of *Cycadeoidea dacotensis* as Yale trunk No. 214, illustrated at length in my American Fossil Cycads (Structure), Plates XXXV–XLII, and especially the handsome State University of Iowa flower-bud shown in the colored frontispiece and on Plate XXXIV.

While likewise, bearing in mind that the present rectification is only one of convenience, this same fate of relegation to *Cycadeoidea dacotensis* apparently awaits the fine National Museum trunk nominated as "the type and only perfect specimen" of *Cycadeoidea Minnekahtensis;* for it too is a form with medium to large-sized fructifications, and of the two accompanying fragmentary paratypes the fine armor slab numbered 24 in the Yale collections and also figured in the original description* has been studied at length and found to be a *C. dacotensis.* Nor can we reconcile either *C. colossalis* or *Wellsii,* the only other species of antecedent description, with the lesser flowered forms to which we wish to turn our attention.

It thus follows from the material now before us and the trunks secondarily referred to by Ward in his original descriptions, as well as from the chronologic order of type discussion, that while *Cycadeoidea Marshiana* is an unassailably well-founded species, its actual characters are very different from those for several years thought to mark it. Instead of being near to and difficultly distinguishable from *C. dacotensis* with large flowers of eighteen to twenty microsporophylls, *C. Marshiana* proves to be a small-flowered type with only eleven or twelve microsporophylls of distinctly reduced form. In fact these flowers are, as described below, the smallest of any in the silicified series so far found complete. That several of the trunks of much smaller growth with far smaller fronds, like *C. rhombica* and the evidently branched *C. nana,* bore even smaller flowers, is known from various small fruits and ovulate cones, but not so far from completè flowers.

These latter, however, appear to be distinct, in consequence of which *C. Marshiana* is now based on (1) the trunks mentioned above as figured under that name in my American Fossil Cycads, (2) those illustrated here, (3) certain other Yale specimens enumerated by Ward,† and (4) the magnificent quadruply-branched specimen several years since transferred from the Yale collections to those of the Paris Museum. While a further specimen requiring examination in this connection is the U. S. National Museum trunk No. 2 figured by Ward as the type of *C. Colei* (loc. cit., Pl. CX).

* Loc. cit., Pl. LXXVIII.
† Loc. cit. and in this Journal, Nov. 1900.

Nor does it, adding yet another word, seem even remotely probable that any of the earlier named Maryland or European Cycads agree with or could ever be found to preoccupy *C. Marshiana;* for the Maryland forms appear to be, in agreement with all European forms, distinctly columnar, while *Cycadeoidea marylandica* (Font.) Capellini et Solms is most like *Cycadeoidea etrusca* Capellini et Solms, the flowers of which have been briefly restudied by the writer thanks to the interest of Capellini.*

It thus transpires that so far as more definitely known the larger branching specimens from Minnekahta are mainly included in the huge, large-flowered *Cycadeoidea dacotensis*, which probably includes *C. colossalis*, *C. minnekahtensis* and several other species, with *C. superba* as a closely related type. The medium-sized specimens, bearing in mind that it is the adult fruit-bearing plant that is spoken of, mostly belong to *Cycadeoidea Marshiana;* and following this well represented type comes, amongst smaller forms of branching trunks, the interesting *C. nana*, further to be mentioned below. But a closer scanning of these various forms need not now be attempted, the only object of the preceding paragraphs having been to fairly explain what the true specific names of the flowers and parent trunks here considered really is.

Though before turning to the description of the flowers of *Cycadeoidea Marshiana*, which is thus the main object of this study, it may, however, conduce to clearness both now and hereafter to observe that the changes in specific assignments which must inevitably follow the closer study of the silicified cycads can scarcely be regarded as taking away from the net value of Professor Ward's earlier determinations and descriptions based on macroscopic characters alone. In 1899 the writer published his opinion that it was fortunate for scientific uniformity that Professor Ward had studied the entire American series then known; and this view still seems just. True enough, when the trunks of the greater Yale collections assembled by 1902 came to be searched rigorously for the purpose of matching isolated parts of trunks, the catalogue list was reduced by about forty numbers, it being found that in some instances parts of one and the same trunk had reached the Museum in different collections, sometimes received several years apart. And it also became evident that the great branching trunks of the Minnekahta series as thus frequently dissociated in the course of collecting had in considerable part simply defied accurate assignment on the basis of outer characters.

But, on the other hand, all subsequent study has indicated the substantial accuracy of the entire specific alignment first

* See Historic Fossil Cycads, this Journal, Feb. 1908.

proposed for the unbranched series of trunks from Black Hawk including *Cycadeoidea Jenneyana*, *ingens*, *aspera*, *formosa*, *Stilwelli*, *excelsa*, and *rhombica;* so that in the end the somewhat arbitrary use of macroscopic characters has proven an indispensable convenience. For not only is there rather more connectedness in the determination of the American series of species than in the nearly equal number of European forms, but these latter are on last analysis quite as distinctly based on macroscopic diagnoses and even more destined to revision.

* * * * * * *

The *Cycadeoidea Marshiana* trunk No. 3 of the Yale collection, as at once appears in figure 1, bears many partly eroded bract groups irregularly scattered all over the lateral armor surface, plainly indicating the position of the deeply imbedded fructifications. And as already noted, attention was first directed to these rather inconspicuous flowers while searching for younger fruits of *C. dacotensis*, it being at the time overlooked that such even when very young develop a huge peduncular axis as in the examples shown in Plate XXXIX, fig. 1, and on Plate XLI of the American Fossil Cycads. A partly unexpected result was therefore obtained when the cutting of sections from core No. II of the series here illustrated revealed the presence of the quite full-sized, though apparently not fully matured complete flower of figures 2 and 3. But unluckily the first section, a longitudinal one, did not chance to traverse the floral axis; and it was not until several additional sections were cut that the peripheral synangia were finally observed and the position of the small flowers, no larger than a five centimeter length of a medium-sized lead pencil, accurately located in the core.

It was in consequence much hoped that in the course of the further study of trunk No. 3, a second bud might be found with a non-dehiscent disk in good conservation permitting more perfect sectioning; for the correct technique of course requires two initial sections for the exact location of the first or any other longitudinal section. And the study was carried on until three additional cores were drilled out, these including the very large one illustrated in figures 5 and 6, and alone containing four separate strobili. But none of the new cores yielded an additional disk, although no less than nine more axes were found present, making a total of ten fruits studied in the four cores removed from trunk 3. Only in a single instance was even a trace of a disk found persistent; in section 722, cut from the fourth and last core, one sees a considerable mass of broken down disk tissue just above the cone as indicated at *S*, figure 4. Evidently the disks at times slowly shriv-

elled up in their much enclosed position instead of being early disengaged after pollinial growth. In the eight other axes growth had continued well beyond the disk dehiscing stage so evident in figure 2 *B*; though the basal collar is always dis-

FIG. 1.

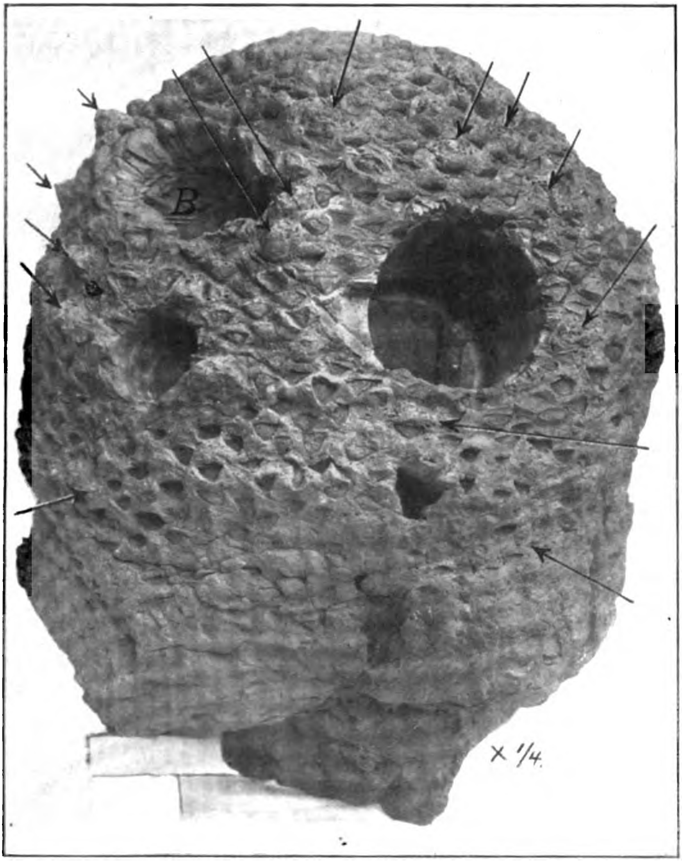

FIG. 1. *Cycadeoidea Marshiana.* × 1/4.

From Minnekahta, South Dakota; Yale Collection No. 3.—View showing drill holes, and a small cavity at *B* due to breaking away or non-conservation of a small branch.

The larger drill hole yielded the core from which was cut the sections of figures 5 and 6, and the smaller beneath the cavity *B* the bisporangiate strobilus of figures 2, 3, and 3 *A*. The arrows, some fourteen in number, locate various additional bract-enclosed axes, and many others are present. It appears that most if not all of these fruits belong to a single fertile period, the fruits being in some preëmbryonal stage.

tinct, it being held certain that these flowers uniformly bore disks—were truly bi- or "amphisporangiate." In the sections cut from the largest cone, figure 5, the testal walls are clearly outlined by zonal conservation and one may plainly see the more or less collapsed nucellar sacks in the seed interiors.

Notwithstanding this well advanced ovulate growth of the great majority of the axes of trunk 3, it still seems probable that amongst the numerous remaining bract groups, various of which are indicated by the arrows of figure 1, a few may still

Fig. 2 *A*.

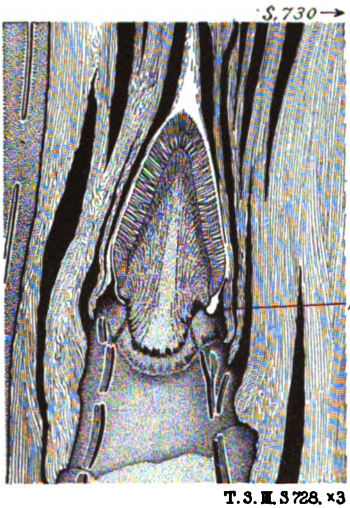

Fig. 2 *B*.

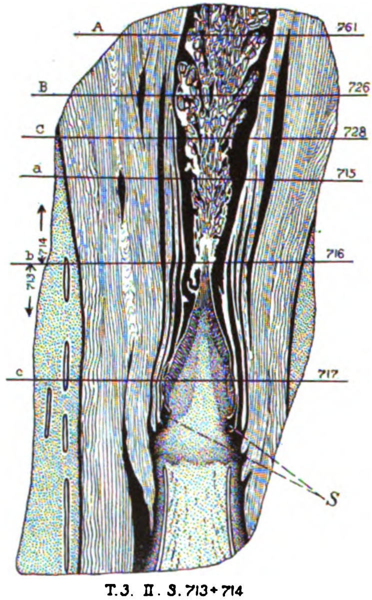

Fig. 2. *Cycadeoidea Marshiana*. [*A* × 2·5. *B* × 1·5.]

A. Longitudinal section through ovulate cone, fruit No. 3 of Yale trunk No. 3. As the section finally passes out a little to one side of the strobilar axis the terminal brush does not appear. At *S* remnant of disk collar. Compare with figure 7.

B. Longitudinal section of bisporangiate strobilus of Yale trunk No. 3, composed from two nearly tandem sections, Nos. 713 and 714. The disk has either wilted loose prematurely or is on the point of dehiscence, having left at *S* precisely the same remnant of the campanular insertion as at *S* in *A*.

The microsporophyll rachides with short pinnules appear in solid black, but the decurved rachidal tips do not traverse the central axis, the section being slightly tangential, as may be exactly noted in figure 3 *A* of the transverse section 761. Compare by number or letter the complementary transverse sections as illustrated in figure 3.

enclose complete flowers. But in view of the results recited further search was abandoned and the parts of core No. II

were cemented together again in their natural place for the completion of the oriented sections showing the structure of the entire flower bud, as now to be described.

FIG. 3.

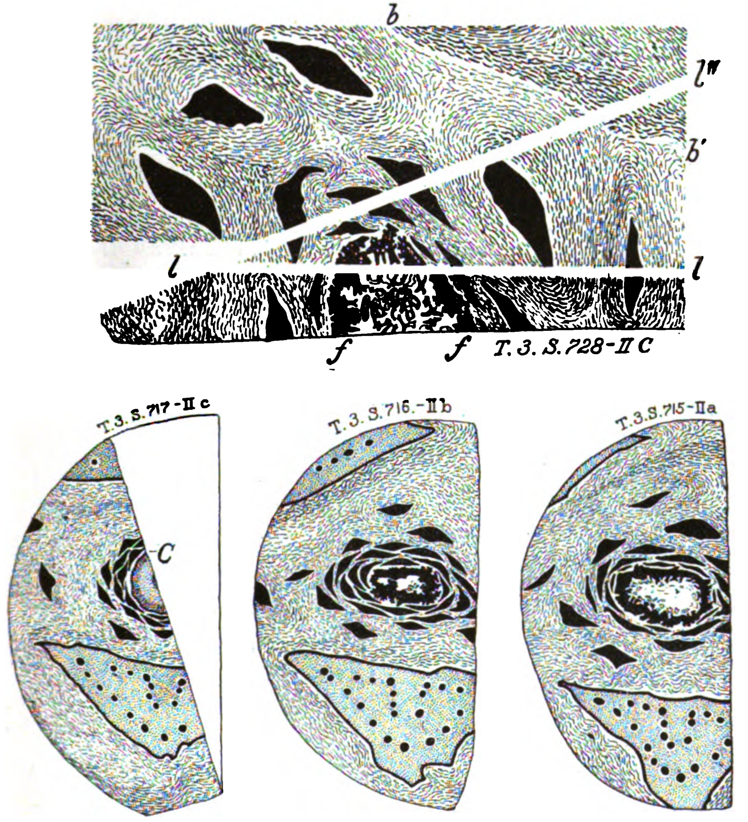

FIG. 3. *Cycadeoidea Marshiana.*

The series of transverse sections cut from the bisporangiate flower bud No. 2 of Yale trunk No. 3. The exact level of each is indicated by letter (*B*, *C*, *a*, *b*, *c*), and by section number in the longitudinal view, figure 2 *B*.

Observe that the upper figures are more enlarged than the lower ones. At *f* are the fronds, and *b b'* shows the line where the bract ramentum rests in that of a leaf base.—*ll* and *ll'* mark the trial saw cuts spoken of in the text.

Note that the lower section *c* (S. 717) traverses the level of disk dehiscence, while in the two succeeding sections *b* and *a* the disk collar is continuous. Between these two sections *b* and *a* the ovulate axis finally terminates, and between *a* and *C* (No. 728) disk division into the fronds *f*, *f* occurs.—Continue to figure 3 *A*. For exact size compare with figure 2 *B*.—Cf. continuation fig. 3 *A*.

The Flower of *Cycadeoidea Marshiana.*

I. Yale trunk No. 3.—Figures 2, 3, etc.

The orientation of the series of sections of the sole complete flower obtained from trunk 3 will at once be apparent on inspection of the figures. And it will doubtless be granted that the lesser difficulty of limitation to this single example is more than compensated for by the resultant fixing of the period of disk dehiscence at a given immature stage of ovulate growth, even more accurately than in *Cycadeoidea daeotensis.* Moreover the series taken as a whole is nearly enough ideal to display the floral features with precision; while the traversal of transverse sections 717, 726 and 728 by trial saw-cuts and the necessity of using approximately tandem sections for the longitudinal view figure 2*B* has in nowise taken away from Mr. Barkentin's figures. These have all that excellence lent alone by the study of serial sections by both author and artist with free use of photographs and joint verification of every detail.

Fig. 3 *A*.

Fig. 3 *A*. *Cycadeoidea Marshiana.* Section 761, Yale trunk No. 3. × 10.

Supplementary figure in continuation of transverse series shown in figure 3. The section traverses the microsporophylls at a point just beneath the down-curving of the rachidal apices, the grouping of which plainly appears at the center of the figure.

In this camera lucida drawing by the writer the ornate sculpturing of the sporophylls, and especially the grouping and attachment of the synangia plainly appear.

The longitudinal section 714, figure 2*B*, stands at right angles to the base line of the present section, and cross reference to the several figures shows the location of all the sections.

The silicification of the armor of trunk No. 3 does not extend to the clear indication of the finer tissues of the enclosed flowers, although all larger tissue zones and features are clearly stained and outlined. So that in the bisporangiate bud one clearly sees the main anatomical details, the peduncle with its wood zones, the course at least of the bundles given off, the bracts enveloped deeply in hairy ramentum, the outlines of the disk and component fronds with the position of the disk and rachidal bundles (figure 3*A*, section 761), the pin-

nules and attached synangia with quite well-marked traces of wall structure, and finally the central ovulate cone with its large pithy axis bearing the young zone of seed stems and interseminal scales. And we can also see traces of the sporan gia, either a young condition being indicated, or pollen shed-

Fig. 4.

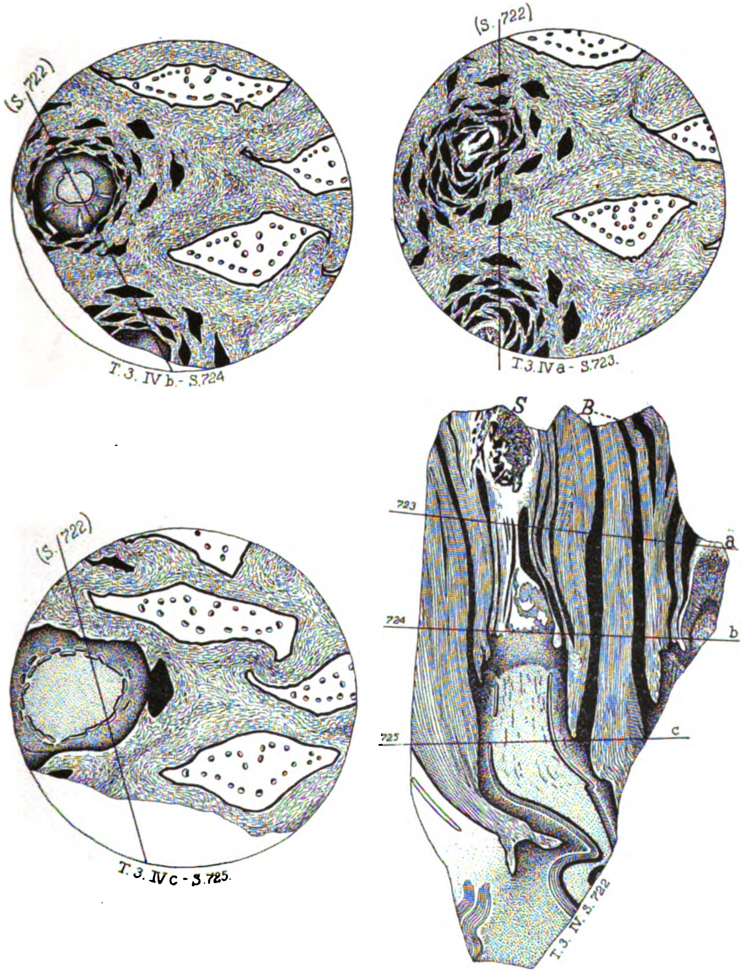

Fig. 4. *Cycadeoidea Marshiana.*

Longitudinal and serial transverse sections through core in which are embedded two adjacent ovulate cones. × 3/2 nearly. The secant lines in sections 723–725 indicate the position of the longitudinal section 722. In the latter the position of the foregoing transverse sections is indicated. At *S* in 722 there is a mass of tissue left by the breaking down of a disk.

Fig. 5.

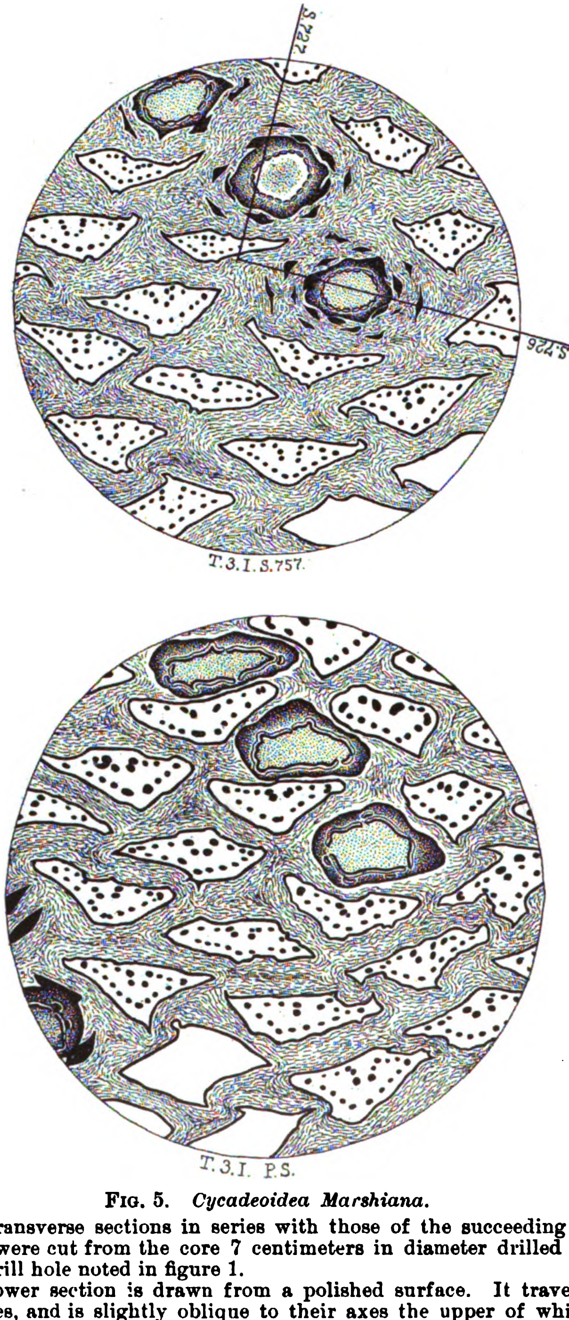

Fig. 5. *Cycadeoidea Marshiana.*

Two transverse sections in series with those of the succeeding figure 6. All five were cut from the core 7 centimeters in diameter drilled from the larger drill hole noted in figure 1.

The lower section is drawn from a polished surface. It traverses four peduncles, and is slightly oblique to their axes the upper of which is cut from 12 to 18mm more proximally than the lower. Continue to figure 6.

FIG. 6.

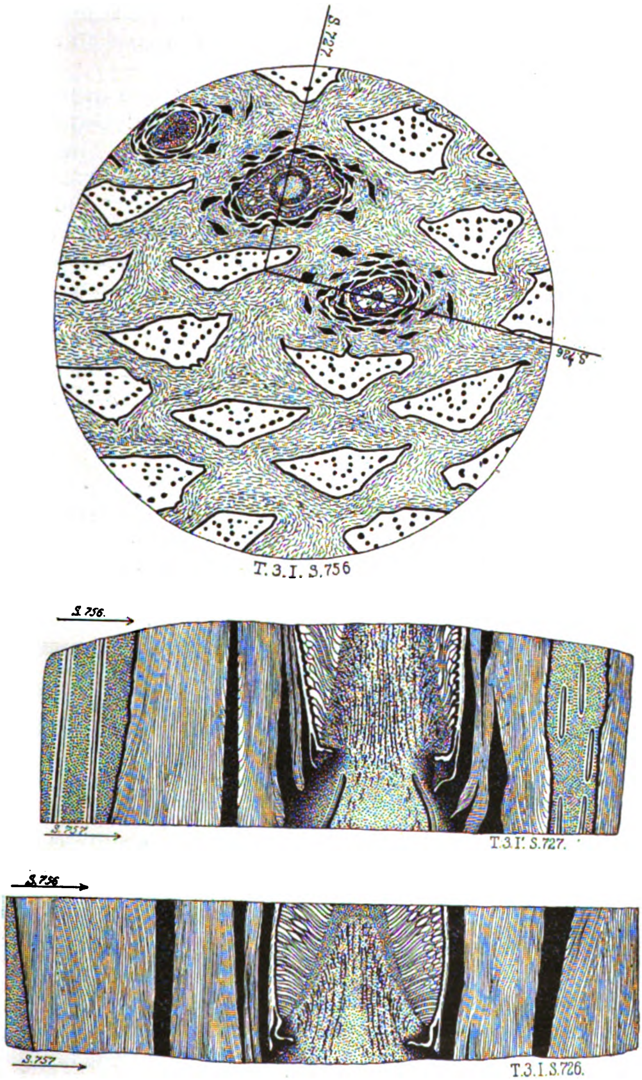

FIG. 6. ***Cycadeoidea Marshiana.***

Three sections in series with those of figure 5. The upper transverse section No. 756 passes at a distance of 8 to 12^{mm} above S. 757, figure 5; and the two lower longitudinal sections 726 and 7 lie between S. 757 and S. 756 at exactly right angles to each other as marked. Each of these sections traverses the basal part of an ovulate strobilus in which the young seeds are fairly distinct, and may even approach full size; though fertilization is not thought to have occurred.—S. No. 756 and the preceding SS. of fig. 5 are shown ×7/8, and SS. 726, 7 are ×2 nearly.

ding and sporangial collapse having occurred. The seeds show but little structure, being distinctly younger than those of figure 6, already mentioned as showing testal zones and distinct nucellar sacks.

Cell walls are however generally obscure: one cannot make out the bract structure; and similarly the disk and rachides, though very clearly outlined, appear only as an indistinctly granular groundmass traversed by lighter colored traces of the bundles, fortunately continuous enough to show the pattern of the bundle system. But even so the assemblage of fairly well-conserved features taken together with the entire outline of all organs affords a clear view of the form and general structure of the flower.

On noting that seven rachides are to be seen in sections 726 and 728, and then comparing the series of decurved apices in section 761, figure 3a, it becomes evident that the disk divides into twelve small microsporophylls as in the young and quite small flower of *Cycadella wyomingensis* (American Fossil Cycads, figure 93 I) and the very large flowered *C. ingens* of the columnar series, instead of dividing into seventeen or eighteen large staminate fronds as in *C. dacotensis* and various of the *Williamsonia* staminate disks or flowers. The point at which the campanula splits into the separate fronds is accurately located between sections 715 and 728, figure 3, at a hight of about a centimeter above the apex of the ovulate cone, which is not a precisely fixable point because ending as a long thin brush of sterile organs at last almost hair-like.

The length of the microsporophylls can only be estimated within fairly close limits because of the destruction of the mid-region of the bud summit by erosion; but estimating this loss at about one centimeter and adding for the decurved tips 1·5 centimeters, the full length of the microsporophylls appears to have been about 5·5 centimeters. Whence after allowing for the diameter of the ovulate cone, the flower as imagined in an arbitrarily expanded form would have a diameter of ten or twelve centimeters.

The *rachis* and *pinnules*, as one readily sees in the longitudinal section fig. *2B* and the transverse section fig. *3A*, are much moulded and furrowed by appression faces or even crinkled, but withal in a manner producing ornate patterns where these organs are cut to advantage in regular series. The pinnules are broad of base and must tend to confluence with each other. They are a centimeter long in the mid-rachidal region and diminish much in length towards both base and apex of the frond; so that each frond if laid out flat would have a more or less elongate-elliptical acuminately tipped, pinnately parted to pinnately divided form.

The *synangia* are well enough advanced in growth to outline themselves distinctly, being in reality better conserved than one might expect from the condition of some of the other tissues. But the individual sporangia cannot be clearly made out, and no distinct pollen appears. Inasmuch, therefore, as the synangia have only from half to two-thirds the size seen in *C. dacotensis* buds, in which the size agrees with that of Marattiaceous synangial types, either a somewhat young stage of growth is indicated, or as is more likely, an incompletely developed stage due to some failure in floral growth such as would readily have been produced by events leading up to fossilization.

FIG. 7.

FIG. 7. ***Cycadeoidea Marshiana.*** **Yale trunk No. 3.**

S. 756. Ramentum in transverse section,—study suggested for use in determining species. The area shown includes the line *ff* separating the larger leaf-base ramenta from the small bract ramenta. In both cases the hairs are characteristically one cell thick, except that occasionally the leaf-base ramental scales are thicker. [Compare with *Bennettites Gibsonianus.*]

S. 730. Transverse section through core containing two ovulate cones which have shed their staminate disks. The section traverses the outer armor, and cuts through the ovulate cone of the upper axis, but passes above that of the lower. At *l* is the saw cut for the longitudinal section 728 shown in figure 2 *A*, q. v. Natural size.

On the other hand, the possibility that the synangia like the flowers were of small size, and the pollen all shed, should not be lost sight of; and as bearing on this point the supplementary section No. 717 was cut in order to better bring out the fact that the disk bears the same appearance of wilting and dehiscing just above the insertion as in *C. dacotensis* buds, where an approach to floral maturity is seemingly indicated.

But in neither case is it necessary to assume that the staminate frond was normally of much larger size than here seen; while the ovulate zone is already notably older than in the *C. dacotensis* buds, it even being possible that the mature strobilus of trunk 3 did not reach a markedly greater size than in

the largest of the ten axes so far studied. (Cf. fig. 6.)—A fairly well grown or mature *C. dacotensis* cone is shown in my American Fossil Cycads, p. 67, under the name *C. Marshiana*, and on the opposite page 66, under the latter name, a form that belongs to some third species not yet satisfactorily determined. Cone species and the later growth of cones is, however, a long and difficult subject which cannot be taken up in connection with discussion of the partly uncertain growth stage of the flower before us.

II. Flower-Buds of Yale Specimen No. 164.—Figures 8, 9.

This superb silicified cycad was made the subject of special description with reference to branching in my American Fossil

Fig. 8.

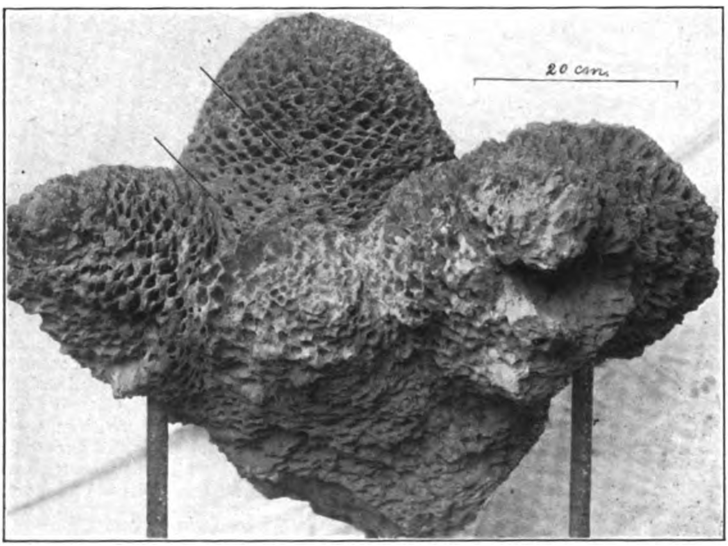

Fig. 8. *Cycadeoidea Marshiana.* Yale trunk No. 129.

Exceptionally handsome trunk with fruits small and young, but of the same type as those of figure 9. Minnekahta, South Dakota.

Cycads (structure), pages 41–43, and illustrated in relief on Plates VII and VIII. Here too, small fruits were supposed to be young until several thin sections showed the presence of mature flowers adjudged to be of the same species as those of trunk No. 3, although sections of the ovulate cones yet require to be cut,—this task not being relatively urgent since no change of name is involved in the specific reference of this cycad here and earlier made.

The first section cut is that of fig. 9 *A*, showing distinct agreement of the staminate disk with the corresponding transverse section from the flower of trunk 3 seen in figure 3, section 728, and in figure 3 *B*. And the meaning of the section was further confirmed by a rigid search all over the surface of the trunk, taken point by point, resulting in the detection of a single additional example, clear of outline but previously overlooked. This flower has not been cut from the trunk, where it appears just as shown in figure 9 *B*. The synangia are apparently larger than in trunk 3, which is really yet another reason for supposing the flower of that trunk to be not quite fully grown. But caution in judging without thin sections is required, here or in the case of any flower or strobilus,—more

FIG. 9.

A *B*

FIG. 9. ***Cycadeoidea Marshiana.***

Two bisporangiate flower buds from trunk 164 of the Yale Collection. (For figures of this trunk see American Fossil Cycads, Plate VIII et seq.)

(*A*) Transverse thin section through the summit of a flower with nine microsporophylls. The section passes at some distance above the ovulate cone, and no decurved tips of microsporophylls appear at the center. Enlarged about twice.

(*B*) Drawing of a portion of the surface of branch (C, Plate VIII, Amer. Fos. Cycads) showing partly eroded flower bud. The mass of synangia and pittings corresponding to the rachides of eleven microsporophylls plainly appear. Shown in natural size.

especially where but a few axes are studied. The number of disk divisions is clearly eleven; so that while the study of this form still rests mainly on macroscopic features, there is little doubt as to its identity.

Probable Habitus of Cycadeoidea nana of Ward.
Figure 10.

The subject of small cycad flowers and the branching habit is further illustrated by the quintuply-branched trunk of fig. 10, consisting in a central stem, two large basal and two lesser lateral branches. This exceedingly interesting specimen was

collected by the writer himself while engaged in private exploration carried on in the Black Hills region throughout the summer of 1902. It was found after some days of patient search at the well known Minnekahta locality, supposedly exhausted by previous collecting. The specimen has an added interest and importance as one of the few trunks found in place. It lay on its side imbedded in a characteristic stratum of straticulate clayey sandstone, and only a few square inches of the upper face of the main stem could be seen.

Had this handsome and finely conserved specimen been eroded out like most American and the Italian Cycadeoideas, the basal branches, which were already fractured across their

FIG. 10.

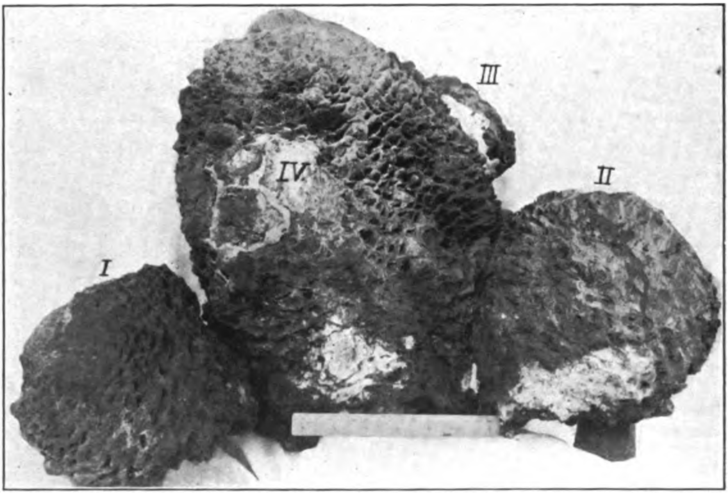

FIG. 10. *Cycadeoidea nana.* × 1/6.

The main central stem gives rise to the two low-set branches I and II, and the smaller lateral branches III and IV. That numbered IV is the smallest and fails of the good preservation seen in the others.—Near the Roman numeral IV is located the ovulate fruit mentioned in the text.—[Minnekahta, S. D., Author's Collection.]

junction with the main stem, would have become separated, and probably could never have been brought into their natural position. It is thus by good fortune that the trunk adds precious testimony to our knowledge of the branching types.

Moreover, had one of the basal branches been found separated it would in all likelihood have been referred to the species *C. nana*,* hitherto with some reservation regarded as an un-

* See Ward, loc. cit., pls. clvi, clvii.

branched cycad. To this species therefore the trunk should be provisionally assigned. Although a rather young form, several fruits are present, and an ovulate strobilus one centimeter in diameter and about two in length has, in strong contrast to the *C. Marshiana* strobili figured above, the same flatly convex type of parenchymatous cushion as *C. Wielandi.* Whence it follows that *C. dacotensis* with the allied *C. superba*, *C. Marshiana*, and *C. nana*, include a clear succession of forms passing from the largest of compactly branched cycads to lesser and finally small-sized and small-flowered, more freely branched trunks.

The floral indices of this series are therefore distinct; *C. dacotensis* having a larger disk of seventeen or more fronds and *C. Marshiana* a much smaller flower with eleven or twelve fronds, while in *C. nana* the disk is unknown but the ovulate cone varies from that of both the foregoing species in its convex instead of elongate parenchymatous cushion. And as will be illustrated in subsequent studies already fairly complete, this same transition from the elongate primitive type of strobilar axis to a convex or nearly flat parenchymatous cushion is as strikingly illustrated by the strictly columnar species of the Black Hawk localities. There too, an elongate axis is present in the fruits of the great *C. ingens* and the tall *C. Jenneyana*, while the fine columnar trunk *C. excelsa* bears the largest cones with the shortened or reduced axis or cushion type yet seen.

* * * * * * *

A few of the suggestions arising from the present study of small cycad flowers in connection with the trunks that bear them may well be given a tentative record here.

Much stress has been laid in my American Fossil Cycads on the process of branch formation with increased flower output, in view of which *Cycadeoidea Marshiana* and *C. nana* have much interest as now shown to typify the extreme of branch development and floral reduction in the *Cycadeoideæ.* But it is not necessary to assume this family to be a direct derivative of simple stemmed types; its immediate ancestry may have had freely branched forms with much slenderer stems. Even without considering *Cordaites* it is obvious that free branching of gymnosperms and reduction of floral organs are very ancient.

It is then among the Williamsonian tribe that the search for types of branch development and floral reduction must be continued. Nor can the rôle of the threefold process of branching, sporophyll reduction, and acquisition of the angiospermous emplacement in older cycadophytans have been a meaningless one. This course of change must have been in evidence by Permian time, while *Wielandiella* with wholly reduced sta-

mens shows it to have been far advanced in the Trias. It indeed suggests an evolutionary process that may well have been the most significant of all that went on amongst the plants of the early Mesozoic forests.

Even in the Cycadeoidean side line reduction of flowers from primitive crowns had proceeded well beyond the mere limits of floral size in the Angiosperms, and the conviction grows that such changes were the identical ones responsible for the advent of these now dominant plants. Twelve years ago this seemed the first probability. To-day it is a theory undergoing demonstration, whether we regard the Angiosperms as monophyletic or, as seems vastly more reasonable in the light of the once dominant cycadophytan plexus, polyphyletic. Cosmopolitan and plastic races, already ancient of lineage, are better conceived of as moving forward *en masse* with little loss in diversity of features.

FIG. 11.

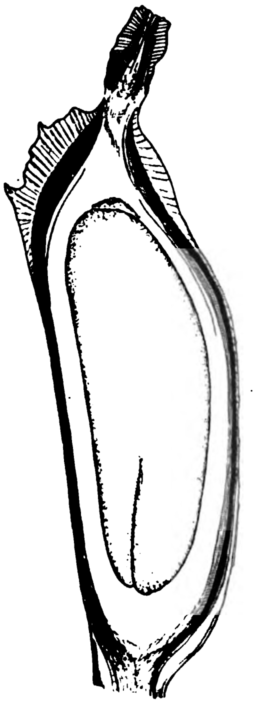

FIG. 11. *Cycadeoidea turrita.* × 25.

Mature seed containing embryo cut in nearly the true median plane showing the micropylar tube of three layers, a heavy inner palisaded, a thin middle, and a lighter outer palisaded layer,—the tube interior being filled with a soft tissue. Two of the five to six wings of the "blow off" appear. These are the smallest mature seeds of *Cycadeoidea* so far known.

Regarding the general outlines of such an evolutionary course, fair inferences were possible with *Cycadeoidea* alone well known. That this type had an ancestry in which spiral insertion of leafy fertile organs on a main axis was as distinct as in the female *Cycas* was obvious. And that these organs were of strictly Cycadalean nature appeared likewise evident before the restoration of *Weltrichia*, equally balanced in its characters between Cycadaceans and Cycadeoideans, or perchance even representing one of those long occulted Medullosans. But with this form before us we know, in fine, that the more or less distinctly monaxial insertion of fertile organs was long retained, that the whorl of stamens with disk growth early appeared, and that concomitant floral reduction and branch formation were at least in part late.

Weltrichia, as an early member of the Williamsonian tribe, of which the habitus is now so fortunately known, *Cycadeoidea*, and *Wielandiella* thus stand in reciprocal relationship. The first is simple, primitive, cycadean, but fairly started on the course of change leading towards angiospermous floral types. The second has by reason of silicification added most to our knowledge, but its xerophytic, stereotyped features have long obscured our conception of how truly generalized the cycadophytans really are in stem leaf and fruit. While the third with its slender freely dichotomized branches and laminar leaves, in reality but little removed from any pinnately net-veined type, has all but completed the process of microsporophyll reduction.

More or less in contrast to this staminate reduction, the complexly organized Cycadophytan seeds are uniformly ancient of type. In their coats are best seen Cycadofilicalean or Pteridospermous features that add not a little in gaining ideas of race relationship; although at the same time both style and stigmatic surface begin to appear as structures of secondary origin and function. It is in the seeds that but recently the distinct resemblances to *Gnetum* have been noted that may go to indicate this as some long persistent non-plastic form that originated when the great races preceding the Angiosperms began to convert Paleozoic structures to Mesozoic needs.

And similarly the hiatus between flower and inflorescence, once held all but impassable, may be but slight if *Tumboa* proves to be another such a laterally related but even older and more stereotyped line; it being quite conceivable that continued reduction of lateral branches bearing, like those of *Cycadeoidea*, flowers derived from strobilar crowns, could finally give rise to Tumboan and other types of inflorescence.

Art. XI.—*The Occurrence of Coral Reefs in the Triassic of North America*;* by James Perrin Smith.

The occurrence, in the strata of past ages, of reef-building corals of modern groups gives us our best record of climatic conditions in those times. The modern reef-builders are now confined to the tropics, and it is only reasonable to assume that they have always been confined to regions where the waters had a tropical temperature.

No corals of any sort are known as yet in the Lower Triassic, anywhere in the world, although the Hexacoralla must have lived somewhere during that time, since they are known before and after it. In the Middle Triassic of the Alpine province reef-building corals occur, but are not abundant enough to form reefs. They are not yet described from any other region. Towards the end of the Upper Triassic reef-building corals became abundant in the Alps, where they have long been known, and where they formed genuine reefs that had an important influence on the topography. There they extend up to latitude 45° N., showing that in this epoch the Alpine province enjoyed a warm climate. The chief coral zone of the Alpine province occurs in the Noric epoch of the Upper Triassic, not far above the rich ammonite limestone of the Karnic epoch. The occurrence of this same coral fauna, in the same stratigraphic position, in localities far removed from the Mediterranean Region would be ample proof that the favorable conditions were widely distributed over the earth in this epoch. This would also tend to show the probability of the amelioration of the general temperature, at least over the northern hemisphere, during this epoch.

Reef-building corals have been found in the Himalayas in India in the Noric beds, but are not yet described; their evidence as to physical conditions is just as positive, even though we do not yet know by what names they should be called.

In his studies of Triassic stratigraphy in northern California the writer was long ago impressed by the fact that the limestone there resembles coral rock, and fragments were found that suggested remains of corals. Several years ago this was confirmed by the discovery of abundant corals in many places on the limestone ridge between Squaw Creek and Pitt River, and on Cow Creek south of Pitt River. The general section of the Triassic of Shasta County is given below, to show the position of the coral zone.

In the section given above, the thickness of the beds is only approximate, varying from the maximum near the junction of

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Triassic Section of Shasta County, California.

					Thickness
Upper Triassic	Noric	Brock Shales		Black slates, with *Pseudomonotis subcircularis*.	? 800 ft.
Upper Triassic	Noric	Hosselkus Limestone		*Spiriferina* beds, hard siliceous limestone, full of brachiopods.	100 ft.
Upper Triassic	Noric	Hosselkus Limestone		Coral zone, with numerous reefs, of Astræidæ, *Isastræa*, *Stephanocœnia*, *Astrocœnia*, *Thamnastræa*, and *Thecosmilia*.	
Upper Triassic	Karnic	Hosselkus Limestone	Zone of *Tropites subbullatus*	*Juvavites* beds, hard limestone, with abundant ammonites, *Juvavites*, *Gonionotites*, *Discophyllites*, *Tropites Telleri*, *T. laestrigonus*, etc.	50 ft.
Upper Triassic	Karnic	Hosselkus Limestone	Zone of *Tropites subbullatus*	*Trachyceras* beds, shaly limestone, with *Tropites subbullatus*, *T. torquillus*, *T. Dilleri*, *Discotropites sandlingensis*, *Paratropites*, *Trachyceras Lecontei*, *T. shastense*, etc.	50 ft.
Upper Triassic	Karnic	Hosselkus Limestone		*Halobia superba* shales, calcareous shales, full of *Halobia superba*, and a few crushed *Trachyceras*.	100 ft.
Upper Triassic	Karnic			*Halobia rugosa* slates, black argillites, with *Halobia rugosa*, and crushed *Trachyceras*.	? 150 ft.
				Unconformity ?	
Middle Triassic	Muschelkalk	Pitt Shales		Black siliceous shales, altered tuffs, and igneous rocks, with *Ceratites* conf. *humboldtensis*, *Ptychites*, etc.	? 1500 ft.
				Unconformity	
Upper Carboniferous				Nosoni tuffs and shaly limestones, with *Fusulina elongata*, etc.	
Upper Carboniferous				McCloud limestone, with *Fusulina robusta*, *F. cylindrica*, etc.	

Squaw Creek and Pitt River, to less than half so much on the North Fork, 15 miles to the north, where the limestone almost disappears entirely.

The *Tropites subbullatus* beds are divided into two zones, each about fifty feet thick. In the lower are numerous *Tropites subbullatus*, *T. torquillus*, *T. Dilleri*, *T. Morloti*, *T. fusobullatus*, *Discotropites sandlingensis*, *Trachyceras Lecontei*, *T. shastense*, *Arcestes pacificus*, *Clionites*, *Halobia superba*, and many undescribed species of *Tropites*, *Trachyceras*, etc.

In the higher division, the *Juvavites* or *Atractites* beds are

many, *Juvavites subinterruptus*, *J. subintermittens*, *J. Edgari*, *Tropites laestrigonus*, *T. Telleri*, *Homerites semiglobosus*, *Discotropites Theron*, *D. Laurae*, *Pinacoceras rex*, *Margarites senilis*, *Gonionotites*, *Metasibirites*, *Choristoceras*, and many other species, new and old, *Tropites* of the group of *T. Telleri*, *Discotropites*, of the group of *T. Laurae*, *Atractites* and *Dictyoconites*.

A few feet above the highest *Juvavites* beds lies the coral zone with reefs made up chiefly of *Astraeidae*, *Isastraea profunda*, *Phyllocoenia* cf. *decussata*, *Montlivaultia* cf. *Mojsvari*, *Thecosmilia* cf. *fenestrata*, *Stephanocoenia* cf. *juvavica*, *Thamnastraea* cf. *rectilamellosa* *Spongiomorpha* cf. *ramosa*, etc.

This coral zone was found from near Pitt River, east of DeLamar, northward to the North Fork, always in the same horizon, between the *Tropites* limestones and the *Pseudomonotis* shales.

A few miles south of Pitt River, near the junction of Cedar Creek with Little Cow Creek, the Hosselkas limestone outcrops again, and the coral zone is here well developed. The thickness is not so great as north of Pitt River, being reduced to not much more than one hundred feet, the *Tropites* beds having almost disappeared. Here the writer found in the coral zone banks or reefs of *Thecosmilia* cf. *fenestrata*, *Isastraea profunda* Reuss, *Stephanocoenia* cf. *juvavica*, *Latimaeandra* cf. *eucystis*, and *Thamnastraea* cf. *rectilamellosa*.

At this locality, as on Squaw Creek, the coral zone lies well up in the Hosselkus limestone, and below the *Pseudomonotis* shales.

In the Blue Mountains of northeastern Oregon, in Baker County, at Martin's bridge, near the junction of Paddy Creek with Eagle River, the writer discovered in 1908 a small coral reef in the Upper Triassic limestones, of which a section is given below.

It will be noted that this section is entirely different, in the lithologic sequence, from that of Shasta County, California. Nothing lower than the *Halobia* shales was found, and the writer could not determine just what part corresponded to the Hosselkus limestone, since the *Tropites* beds were not exposed, if they are present in that region. Nor could the *Pseudomonotis* shales be found above the coral zone, probably being represented by the barren limestone. The lower shales, with *Halobia* cf. *superba*, were also found at the junction of the two forks of Eagle River, at Anthony's hydraulic mine, but there the limestones that should contain the coral reef are crystalline, and the fossils destroyed. Massive limestone is abundant on the North Fork of Eagle River, but they are everywhere changed to marble.

Section on Eagle River, Baker County, Oregon.

		Thickness
Upper Triassic	Massive limestone without visible fossils.	60 ft.
	Dark brown argillaceous shales, with *Halobia* cf. *austriaca*, and other species of *Halobia*, and *Daonella ?*	100 ft.
	Thin bedded limestone, with banks of corals, *Thecosmilia norica Frech*, *Spongiomorpha* cf. *acyclica* Frech, *Montlivaultia norica Frech*, *Heterastridium conglobatum* Reuss.	40 ft.
	Barren shales.	300 ft.
	Massive limestone without fossils.	100 ft.
	Calcareous shales, with *Halobia* cf. *superba*, *H.* cf. *salinarum*, *H.* cf. *austriaca*, *Dittmarites* sp. ? etc.	30 ft. visible

Some years ago Mr. H. W. Turner discovered some corals in limestone in Dunlop Canyon, Pilot Mountain, near Mina, Esmeralda County, Nevada. These were sent to the writer, who pronounced them Jurassic, as reported by J. E. Spurr* upon this identification. A recent examination of these corals has shown them to be more probably of Upper Triassic age, which is in perfect accord with the stratigraphy. The species determined are: *Montlivaultia* cf. *marmorea*, *Astrocoenia* cf. *Waltheri*, and *Pentacrinus* sp. indet. The two species of coral are well known forms in the Noric beds of the Alps, and *Astrocoenia Waltheri* occurs also in the Noric coral zone of Shasta County, California. The Lower and Middle Jurassic of the Great Basin area are not known in the coral-reef facies anywhere.

A few years ago Dr. G. C. Martin, of the U. S. Geological Survey, discovered in the region of Cook's Inlet, Alaska, some coral-bearing limestones. Among the specimens sent by Dr. Martin from this locality the writer has determined: *Isastraea* cf. *profunda*, *Thecosmilia* cf. *fenestrata*, *Phyllocoenia* cf. *decussata*, *P.* cf. *incrassata*, *Astrocoenia* cf. *Waltheri*, *Montlivaultia* cf. *Mojsvari*, and *Spongiomorpha* sp. indet.

This coral fauna is undoubtedly the same as that in the lower Noric zone of Shasta County, California, and has several species in common with that fauna.

This discovery of reef-building corals in Alaska extends their range northward from 45° in the Alps, and in the Blue Mountains of Oregon, to 60° N. Lat. The coral zone in California, Oregon, Nevada, and Alaska belongs to the same hori-

* Bull. 208, U. S. Geol. Survey, p. 102, 1903.

zon, and contains the fauna of the classic Zlambach beds of the Fischerwiese in the Tyrolian Alps, that is of the Noric horizon of the Upper Triassic.

The group of Astraeidae is abundant in all these localities, except in the Blue Mountains, and since they are still important reef-builders, and now confined to the hottest parts of the tropics, where the temperature does not fall below 74° F., it is reasonable to suppose that in Triassic time they lived under approximately the same conditions. This makes it probable, if not certain, that the sea had a tropical temperature up to 60° N. Lat., at least in the Pacific Ocean.

Speculations as to ancient temperatures of the sea are interesting, but of much more importance to geologists is the fact that this Noric coral fauna gives us a new and distinct benchmark, which in its marked characters and wide distribution equals that of the zone of *Tropites subbullatus*, and enables the positive correlation of strata that heretofore have been a puzzle to stratigraphers.

Stanford University, California.

Art. XII.—*The Ordovician Outlier at Hyde Manor in Sudbury, Vermont;* by T. Nelson Dale.*

In a paper on the geology of the north end of the Taconic Range† the writer called attention to the generally divergent strikes of the Lower Cambrian and Ordovician in the town of Sudbury, Vt., as a key to the perplexing geology of the western side of the Taconic Range. These were regarded as pointing to a crustal movement at the close of Lower Cambrian time which raised the Cambrian beds, west of the later formed axis of the range, above water, and to their submergence in Ordovician time, which was followed, at the close of Ordovician time, by another movement which refolded the Cambrian beds with the Ordovician, in places producing a folded overlap possibly accompanied by minor faulting. One of the pieces of evidence offered was a small outlier of Ordovician limestone in what was then the golf course of Hyde Manor, about 1½ miles SSE. of Sudbury village and 5½ miles about WSW. of Brandon, in Rutland County, Vt.‡

Dr. Rudolph Ruedemann, Assistant Paleontologist of New York State, in a recent paper§ reproduced a part of the writer's plate from this Journal and referred to the outlier in these words:

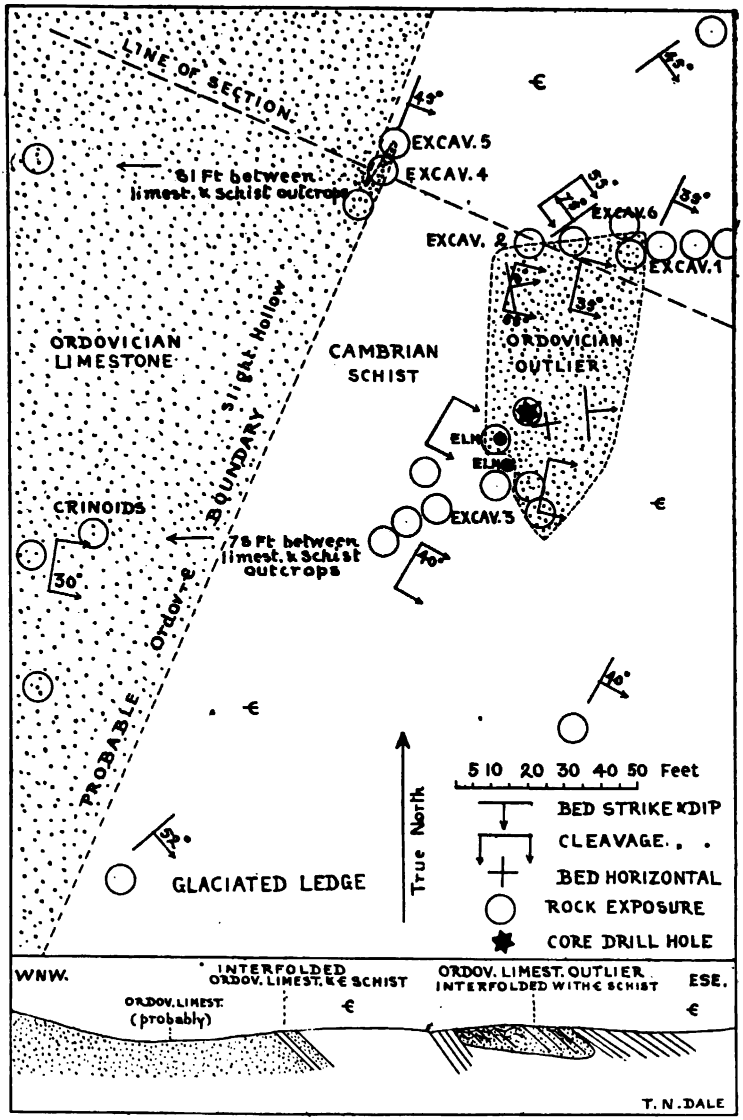
"It is there quite probable that the whole folded plate of Cambric rocks has been pushed along a slightly inclined fault plane from the east over the Lower Siluric rocks, and that the outlier of Stockbridge limestone does not rest in a small syncline of the Cambric, as it would seem, but protrudes from below the Cambric or is a "Fenster," as the European geologists term it (an outlier of younger rock protruding through older rock in consequence of extensive overthrust and partial weathering away of the overthrusted mass)."

In July and August, 1910, the writer spent a few days at Hyde Manor in order to determine the real relations of the outlier and with the aid of two men and dynamite four excavations were made. The distances between outcrops and excavations were measured with a steel tape. Thin sections of the schist underlying the outlier on the north side and overlying it on the east were examined microscopically to fix the directions of bedding and cleavage. In May, 1911, the

* Published by permission of the Director of the U. S. Geol. Survey.
† This Journal, Ser. 4, vol. xvii, pp. 185–190, pl. xi, 1904.
‡ Ibid., p. 187, footnote, also p. 189, middle, pl. xi, black dot on section.
§ Rudolph Ruedemann: Types of inliers observed in New York, N. Y. State Museum Bull. No. 133, 5th Rept. of the Director, 1908, Albany, 1909, pp. 190, 191, fig. 33.

FIG. 1.

THE ORDOVICIAN OUTLIER AT HYDE MANOR, SUDBURY, VERMONT.

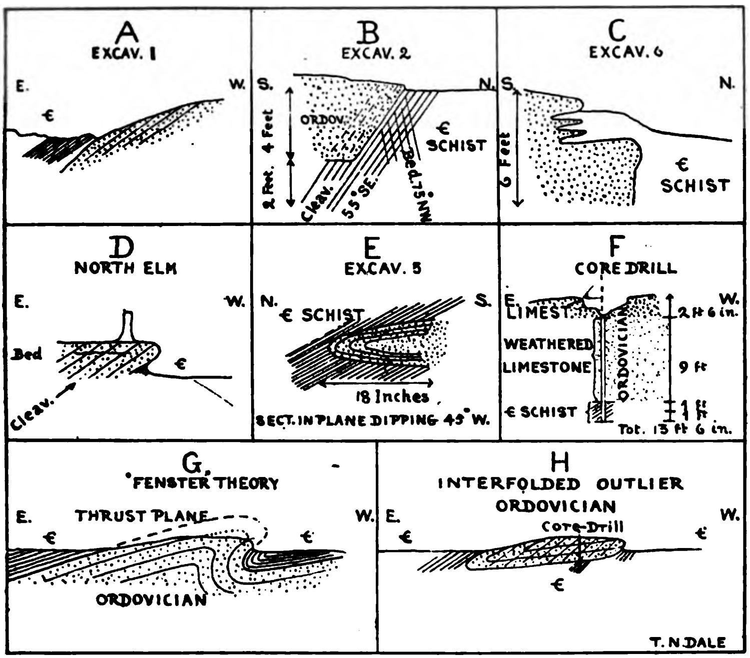


locality was again visited and in company with Messrs. Arthur Keith, E. O. Ulrich, and C. W. Hayes of the U. S. Geol. Survey. More dynamiting was done at one old point and two

new ones. The Ordovician age of the outlier was definitely established by the admission by Mr. Ulrich of the finding of a Streptelasma and crinoids in it on a previous visit. Finally through the kindness of the late Mr. Fletcher Proctor, President of the Vermont Marble Co., the writer was also enabled to have some core-drilling done, which was accomplished in December 1911.

The results of all the excavations and of the core-drilling, and the structure at the important outcrops, are shown on the

FIG. 2.



map (fig. 1) and also in the diagrams of fig. 2. The details are given in the following paragraphs.

Excavation 1 (fig. 2, A).—A trench was first dug from a large outcrop of Cambrian schist east of the northeast corner of the outlier, and a continuous exposure of the schist obtained to its eastern edge on the north. Then blasting was resorted to. The schist was found to overlie the limestone and to dip 35° E. The limestone surface dips about the same, but at one point 45° E. Further blasting to a depth of 5 ft. below rock surface reached a small cave with water which stopped operations. The foliation of the limestone here dips about 35° E.

Excavation 2 (fig. 2, B).—At the northern edge and near its western side schist and limestone were found in contact along a steep E.-W. line, but at a depth of 5 ft. the schist was found to underlie the limestone. Both rocks have a cleavage foliation dipping 55° roughly E. But that of the schist dips SE. while its bedding dips 75° NW. and the lower contact surface of the limestone about 8° E. That this probably corresponds to bedding is shown at a point east of one of the elms, where a small plicated bed of dolomite in the limestone is about horizontal and its plications strike N. 15° W., which is one of the strikes typical of the Ordovician in Sudbury. Near the elm this horizontal bedding crosses a low easterly dipping cleavage, but on the east side of the outlier the small dolomite beds dip east, about with the cleavage.

Excavation 3.—Here a trench was dug 3 ft. deep through soil to the schist and this was exposed by blasting to a depth of 14 inches. The schist foliation dips 40° eastward.

Excavation 6 (fig. 2, C).—A trench was dug from the Cambrian schist north or northeast of the northeast corner of outlier, and the contact of schist and limestone was exposed by blasting. Both rocks were found to be interfolded in a direction at right to the strike but their relations deeper down were not determined.

Outcrops near elms (fig. 2, D).—These elms are on the west side of the outlier. One is growing on it, and schist crops out in contact with limestone and has a foliation dipping east under it. South of the other elm the two rocks are within a few inches of each other.

Excavations 4 and 5 (fig. 2, E).—Here a little trenching exposed a surface of schist 10 ft. long doubled on itself and embracing on the south a limestone fold, 5 ft. thick at its widest part. Two openings were made: one on the line of section showed the limestone dipping about 45° E. between two schist masses to a depth of at least 5 ft. The other exposed the apex of the fold with an axial plane dipping 45° E. The bed surface of the apex (not its solution surface) lies in a vertical E.-W. plane and the schist surrounds the apex. The strike is N.20E.

Limestone ledge west of outlier.—This contains crinoids and has a marked foliation dipping eastward and entered on map as cleavage. The course of bedding is not clear.

Core-drill hole (fig. 2, F).—In May, 1911, one or two charges of dynamite were put in at the point indicated on the map by a star which is about 10 ft. NE. of the northern elm. The limestone became exposed to a depth of 2 ft. 1 in. At this depth Mr. Charles E. Connell, Supt. Brandon Marble Co., on Dec. 1, 1911, had a core drill put in, using crushed steel for an abrasive. After penetrating 5 inches of limestone the drill crossed 9 ft. of soft rock, which it ground up mostly into sand. This effervesces strongly with dilute HCl and under the microscope shows particles of calcite, quartz and schist. The magnet extracts considerable fine steel due to the abrasive. On Dec. 2 the drill struck

solid schist and went a foot into it. At the end of another foot the core barrel became clogged and was left in the hole with its core. As the limestone of the outlier contains some dark sericitic streaks, the calcitic, quartzose sand with schist particles, brought up by the drill, is evidently finely ground weathered limestone. The cores obtained consist of 4·4 inches of limestone, and 4·5 inches of schist in 9 pieces. The pieces of schist all have a marked easterly dipping cleavage and one piece, an inch thick, has a quartz lamina crossing the cleavage. The diameter of this core along the cleavage is 2½ by 2¼ in.*

Conclusions.—The isolated mass of Ordovican limestone on the old golf course of Hyde Manor in Sudbury, Vt., is surrounded and underlain by schists of Lower Cambrian age upon which it rests unconformably and with which it is interfolded in synclinal attitude, and with which it is also interfolded on a part of its northern side in a direction at right angles to the strike, as shown in the section of fig. 1 and diagrams A–F and H of fig. 2. This interfolding of the two formations reappears 40 ft. northwest of the outlier, where a small limestone fold with an axial plane dipping 45° E. has a pitch lying in an E.–W. vertical plane.

In view of the evidence, the application of the "Fenster" theory of Alpine geologists to the relations in Sudbury as shown in diagram G of fig. 2 is quite untenable. Valuable as is the use of the imagination in geological investigations, geological science is still best advanced by careful observation and induction. In this instance the induction has been verified by physical demonstration through core-drilling.

The main mass of Ordovician limestone west of the outlier is probably continuous with that interfolded with the Cambrian schists at excavations 4 and 5, and was, of course, once continuous with the outlier or the beds adjacent to it. A little north of the latitude of the outlier a well marked anticline appears in the Ordovician limestone and the alternation of tongues (synclines) of Hudson schist and of Ordovician limestone shown on the map of the original article on this locality† calls for such an anticline at that point, but the outlier is so near a Hudson schist tongue on the southwest that the anticline can hardly be developed there nor is evidence of its presence obtainable.

The general importance of the outlier is that it is as yet the only point in Western Vermont and Eastern New York where the Ordovician can be seen unconformably on the Lower

* As questions may arise as to this drilling the names of the workmen are given: Geo. McBride of Brandon and Dennis Sullivan of Sudbury. Mr. C. E. Connell of Brandon was also present when the solid slate was struck at depth of 11 ft. 6 in. from surface.

† This Journal, vol. xvii, pl. xi, 1904.

Cambrian, the refolding of these formations at the close of Ordovician time having in other places obscured any original divergence in their strike. As on the eastern side of the Cambrian belt, 2 miles nearly ENE. of the outlier, Cambrian and Ordovician are also in marked unconformity, a westward thrust of the Cambrian on the west side is not consistent with an eastward thrust of it on the east side, which the proposed "Fenster" theory would involve. Minor faulting may well have occurred on both sides in the refolding of two unconformable formations, but it was a secondary element. The prime factors in the relations of the two formations are: a crustal movement at the close of Lower Cambrian; emergence and erosion of the Cambrian beds, followed by their submergence and the transgression of the Ordovician, and finally another crustal movement, but at a slightly different angle from the earlier one, which refolded both formations.

The little outlier is a structural specimen, still *in situ* and small indeed, but preserving the record of one transgression, two crustal movements, and two periods of erosion which affected several hundred square miles of the Taconic region.

Pittsfield, Mass.,
Dec. 16, 1911.

ART. XIII.—*On a Color-Effect of Isomorphous Mixture*; by HORACE L. WELLS.

IT appears to be a general rule that crystals composed of isomorphous substances, in case either or each of these is colored, assume a color intermediate between the colors of the components, and so far as the writer is aware, no unexpected colors have been observed in such mixtures. For instance, it was found in this laboratory several years ago* that the yellow salt Cs_2PbCl_6 and the deep blue salt Cs_2SbCl_6 gave green mixtures, as would be expected.

I have recently observed a curious color-effect when the Cs_2PbCl_6,† which was mentioned above, crystallizes with Cs_2TeCl_6.‡ Both of these salts form bright yellow crystalline precipitates. The lead compound has the color of sulphur, while the tellurium compound has a slightly brighter tint, but their colors are so nearly alike that they can hardly be distinguished without direct comparison. Both of the salts crystallize in isometric octahedra, like K_2PtCl_6 and many other compounds of the same type.

These two yellow salts of lead and tellurium are sparingly soluble in hydrochloric acid, and, therefore, are easily prepared. When the conditions are such that both are deposited at the same time from a solution, the product always has a bright orange-red color, which is the peculiarity of the isomorphous mixture.

This bright red mixture was first observed in connection with the fractional crystallization of about 600 g. of the salt Cs_2TeCl_6. The object of this operation was to find if in this way any separation of tellurium into different elements could be effected, and it is sufficient to say that the results of a very extensive fractionation were entirely negative in regard to any such separation.

The salt used for this systematic crystallization was prepared from crude tellurium, as it was considered best to purify carefully the tellurium of the end-products, rather than the whole of it. When the fractionation had been carried on to a considerable extent, it was observed that the products at the soluble end showed a bright red color, and since this substance was not recognized as any known cæsium double chloride, it attracted attention as a possible indication of the presence of the much-sought impurity in tellurium. However, a qualita-

* Wells and Metzger, Amer. Chem. Jour., xxvi, 268, 1901.
† H. L. Wells, this Journal (3), xlvi, 180, 1893.
‡ H. L. Wheeler, ibid., xlv, 267, 1893.

tive examination of the red product showed nothing unusual in it except the presence of much lead. Then it was found that it could be readily prepared by dissolving cæsium, lead and tellurium salts in hot *aqua regia* and cooling or evaporating to crystallization. It should be explained that the presence of the lead tetrachloride compound in the mother-liquor from the fractional crystallization was due to the presence in the hydrochloric acid solution of a considerable amount of nitric acid which had been used in dissolving the crude tellurium. The lead was an impurity in the latter.

The separate salts Cs_2PbCl_6 and Cs_2TeCl_6 were prepared repeatedly from *aqua regia* solution, but they gave invariably pure yellow products. Under precisely the same conditions when both tellurium and lead were present the products were always red, and there was no very marked variation in this red color when the proportions of lead and tellurium were changed considerably. The red products formed octahedral crystals like the yellow salts, and they were of similar size.

It was suspected that the red substance might be a triple salt of cæsium, tellurium and lead, but analyses of several crops showed that there was no constant relation between the lead and tellurium, and that recrystallization from *aqua regia* changed the composition of a product very much by increasing the proportion of the lead compound. Therefore it must be concluded that the products were isomorphous mixtures.

The following analyses were made of separate crops of the red mixture, where V was obtained by a single recrystallization of IV:

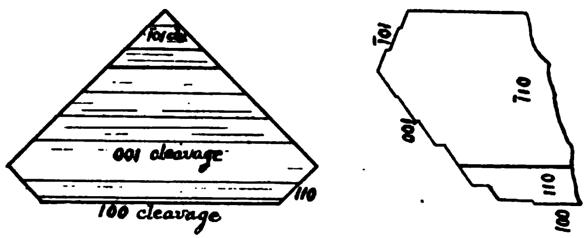
	I	II	III	IV	V
Cs_2PbCl_6	41·2	55·3	47·7	57·0	88·4
Cs_2TeCl_6	57·6	44·3	51·3	43·5	11·4

It is to be noticed that when the two yellow salts in separate, very small crystals are mixed, either dry or under hydrochloric acid, there is no development of any red color, so that it appears that light in passing from one kind of crystal to the other kind gives no unusual effect. Hence it is evident that the effect under consideration is due to the crystallization of the two things together.

Sheffield Laboratory, New Haven, Conn.,
December, 1911.

Art. XIV.—*Lorandite from the Rambler Mine, Wyoming*; by Austin F. Rogers.

I am indebted to Mr. Berger, of Placerville, California, for an interesting specimen from the Rambler mine, near Encampment, in southern Wyoming. This specimen consists of dark fine-grained massive pyrite, upon which are implanted barite crystals and well-formed crystals of orpiment. With the orpiment and barite are associated several orange-red realgar crystals and a single deep red crystal of what proved to be lorandite or thallium metasulfarsenite, $TlAsS_2$. This is the



second known occurrence of lorandite, the original locality being Allchar in Macedonia.*

The crystal mentioned is an imperfect one, of about 4^{mm} size, bounded by the faces of a rhombic prism with interfacial angles of about 90° (calc., 93°) and by three cleavages in one zone, which is at right angles to the prism zone. Using Goldschmidt's orientation,† the prism faces constitute the {110} form and the three cleavages are parallel to {100}, {001}, and {$\bar{1}$01}. The accompanying figure (plan and side elevation) gives an idea of the crystal. All the faces but {110} are cleavages. The following angles measured on the reflection goniometer prove that the crystal is lorandite. The first mentioned angle was measured on a detached fragment,

	Measured	Calculated
100(clv.) : 001(clv.) = ...	52°49′	52°27′
001(clv.) : $\bar{1}$01(clv.) = ...	51°17′	51°49′

while the other angle was measured by mounting the matrix specimen on the goniometer, as it was feared that the crystal would go to pieces if detached from its matrix. The cleavage parallel to {100} is very perfect, that parallel to {001} good, and that parallel to {$\bar{1}$01} fair. The luster is adamantine on

* Krenner, abstract in Zeitschr. Kryst. Min., vol. xxvii, p. 98, 1897.
† Zeitschr. Kryst. Min., vol. xxx, pp. 272–294, 1899.

the cleavage faces, but the prism faces {110} are dull. Even if bright they could not be measured on account of the close proximity of the matrix.

Fragments are prismatic, non-pleochroic, and have parallel extinction. Lorandite is monoclinic, but the cleavages are in the zone of the ortho-axis and so have parallel extinction.

On charcoal lorandite fuses easily to a black globule, coloring the flame bright green. It gives a green flame when fused on platinum wire and alloys with the platinum. In the closed tube it fuses to black globules, giving a black and red sublimate and also minute colorless adamantine crystals of As_2O_3.

The lorandite is soluble in nitric acid, turning yellow. With chloroplatinic acid the solution gives a light yellow precipitate (Tl_2PtCl_6). After evaporating off the nitric acid, potassium iodide gives a yellow precipitate (TlI). The nitric acid solution with hydrochloric acid gives a white precipitate (TlCl).

With the spectroscope this white precipitate of thallium chloride gave a single bright line in the green. With a pure thallium salt the green line appeared at exactly the same position.

Although the blowpipe and chemical tests were made with a very limited amount of material consisting of minute detached fragments, the identity of the mineral with lorandite is well established. The spectroscope proves it to be a thallium mineral and the goniometrical measurements prove it to have the crystal form of lorandite. The blowpipe and chemical tests are confirmatory.

Stanford University, California,
Oct. 1911.

Art. XV.—*The Rate of Decay of Different Sizes of Nuclei, Determined by Aid of the Coronas of Cloudy Condensation;** by C. Barus.

A series of experiments into which I entered at some length and which, though from the nature of the experiment they cannot lay claim to a high order of precision, nevertheless lead to very definite results, are contained in the following table, which is an example of many similar results. These nuclei were produced by X-rays (of moderate intensity) in an aluminum-covered fog chamber, with short exposures to the radiation. The data show that no persistent nuclei of the usual large type appreciably occur, since these, if present, require almost no supersaturation of moist air, for condensation. Moreover, the vapor nuclei of dust-free wet air are not caught in my fog chamber, in the presence of ions, or else their number is specially determined and small in comparison with the nuclei here obtained by the X-rays. This premised, the table gives the relative drop of pressure $\delta p/p$ from p, the lapse of

Table.—Decay of different sizes of nuclei (radius r), the number n present being determined by the coronas of cloudy condensation. $dn/dt = -bn^2$.

$\delta p/p$	t Lapse, sec.	$n \times 10^{-3}$	$b \times 10^6$	$r \times 10^7$
·26	0	73·8	43	·66
--	30	·9	--	--
--	15	1·3	--	--
·28	0	484·	2	·61
--	30	15·7	--	--
·30	15	32·8	3	·54
--	60	6·4	--	--
·33	15	36·8	·4	·48
--	60	29·7	--	--
--	30	29·7	--	--
--	120	21·8	--	--
--	240	6·2	--	--
--	D. f. air	4·4	--	--
·35	15	55·	·1	·43
--	30	113·5	--	--
--	60	86·7	--	--
--	120	55·0	--	--
--	240	38·8	--	--
--	D. f. air	31·3	--	--

* Abridged from the Report to the Carnegie Institution of Washington, D. C.

time, t, between the instant the X-radiation is cut off and the instant of the exhaustion made to catch the remaining ions, together with the number of nuclei, n, per cu. cm. caught, as estimated from the apertures of the corresponding coronas. The column r is an estimate of the size of nuclei, obtained from the drop of pressure δp, and b is the rate of decay. In the table, the nucleation discovered in dust-free wet air at any drop of pressure $\delta p/p$, in the absence of X-radiation is always relatively small, even at the highest exhaustions made. Nevertheless, the persistence of these nuclei, surviving as much as even ten minutes after exposure, is remarkably large, as if all nuclei (vapor nuclei and ions) were eventually caught together. The results, in fact, often point to an almost indefinite persistence. On the other hand, at the lower exhaustion, the number of nuclei soon vanishes. The rates of decay are determined by the usual equation

$$\Delta \frac{1}{n} = b\Delta t \text{ or } dn/dt = -bn^2$$

Briefly, therefore, at a sufficiently high drop in pressure, $\delta p/p = \cdot 35$, the nuclei produced in the presence of ions in dust-free moist air by the (moderate) X-rays, decay at phenomenally small rates, or are almost indefinitely persistent, whereas larger nuclei decay faster in proportion to their size.

Similar facts were brought out by all the other tests with coronas. As $\delta p/p$ decreases, or r the radius of the nucleus increases, b increases at a rapidly accelerated rate, from very small values $b = 10^{-7}$ to enormous values. The small coefficient b is less than 1/10 the normal value obtained for ions with the electrometer (of the order of 10^{-6}), while the large values are nearly fifty times the normal value.

The interpretation of these results is made difficult by the variability of the X-ray bulb. It is safe to assert, however, that the large ions or nuclei produced by the X-rays in dust-free wet air vanish with relatively enormous rapidity, whereas the very small nuclei are almost indefinitely persistent, and that there is a definite relation between the rate of decay and the size of nucleus. If, therefore, we regard these nuclei as water droplets of different sizes, evaporation is rapid until a limiting diameter depending on the intensity of radiation is reached, after which evaporation nearly ceases. It is also probable, that the limiting diameter increases with the intensity of radiation, so that with strong X-rays almost no supersaturation is required. If, therefore, the X-rays produce any chemical body which may go into solution, as has been supposed, the greater or less abundance of this body, supplied by greater or less intensity of X-radiation, would account for larger or smaller persistent nuclei.

ART. XVI.—*A Displacement Interferometer Adapted for High Temperature Measurement, Adiabatic Transformations of a Gas, etc.;** by C. BARUS.

1. *Elliptic Interferences.*—Interferometry by displacement has an advantage inasmuch as the observer never loses the ellipses, even when the displacement is sudden. Their center may always be brought back again to a given spectrum line, by the micrometer. Moreover, since

$$N_c = e\mu \cos R - \frac{e\lambda}{\cos R}\frac{d\mu}{d\lambda} = e \cos R\,(\mu + 2B/\cos^2 R)$$

where N_c is the reduced micrometer reading, e the thickness, μ the index of refraction of the glass plate of the grating, for the wave length λ, R the angle of refraction, and where $\mu = A + B/\lambda^2$, the sensitiveness, may be regulated by decreasing the thickness of the grating, e, by aid of a compensator of thickness e', for the virtual thickness is now $e-e'$. Hence, since for radial motion the sensitiveness per fringe across any given Fraunhofer line is

$$dN/dn = \lambda/2$$

this may be combined with the shift of ellipses controlled by N_c, in any ratio. The limit of this procedure is conditioned by the size of the ellipses or the available size of the field of the telescope, since when $e-e'$ approaches zero the ellipses become enormous.

Furthermore it has been shown† that the quantity $d\mu/d\lambda$ occurring in the value of N_c may be computed preliminarily from observations of $\Delta N_c = N_c - N_c'$, between definite Fraunhofer lines, particularly when the angles of incidence I, and of refraction R, are small. In such a case the constant $3eB = \beta$ nearly, where $(I=0)$

$$\Delta\mu = B\,(1/\lambda^2 - 1/\lambda^2_E),\ \Delta N_c = \beta\,(1/\lambda^2 - 1/\lambda^2_E).$$

Finally if ΔN is the motion of the micrometer to bring the center of ellipses back to a given line

$$\Delta N = (\mu - 1)\,e'$$

where e' is the thickness of the compensator. If e' is large, one may expect to distinguish between the indices of refraction of a birefringent crystal, when the source of light is polarized. Again when the arms or the interfering beams of light are long, the refraction of a gas and its relation to temperature and pressure are determinable.

* Abridged from the Report to the Carnegie Institution of Washington. Reprinted by permission.

† Carnegie Publications, No. 149, 1911, chap. v, § 44.

In view of these advantages among others, I have constructed a definite form of apparatus for displacement interferometry, specially adapted for general observations, such for instance as I have in view with fog particles. The apparatus is to be light, portable, rigid, with relatively long distance between the opaque orthogonal mirrors M and N, and the oblique mirror or grating, as well as height of mirrors above the arms, and with an easy adjustment for different angles of incidence I, large and small. In the following apparatus, figs. 1, 2, and 3, the distance between the center and either remote mirror is about 35^{cm}. It may easily be enlarged many times. The angles of incidence $I = 15°$, $45°$, and $75°$, are available at once for the given braces, though of course other angles may be used.

The long arms and feet of the apparatus, which in general form is naturally much like a spectrometer, are made of 1/4 inch gas pipe, and the braces are heavy strips of tin plate, bent so as to be U-shaped in cross section, much like umbrella steel, with the ends bolted down. In the drawing (of which fig. 1 is the plan and fig. 2 the elevation) the axles are cylindric or slightly conical. In my own apparatus sufficient rotation, 180°, of the parts was secured by ordinary well-cut gas pipe screws. The long arms of gas pipe *a*, *c*, *d*, *e* are not only convenient for the attachment of objects to be examined, by ordinary clamps, but they admit of a circulation of cold water, so that their lengths remain invariable whatever be the temperature of the environment of air.

The tripod, figs. 1 and 2, carries a standard Q of 3/8 inch gas pipe, which is secured snugly by the cross-coupling R. From this the horizontal rigid arms, *a* and *c*, lead respectively to the collimator A and to the slide micrometer C and they are screwed into R parallel to the plane of fig. 1. The arm *e* which carries the telescope E must be revolvable around Q, a wide axle PP' and braces b'' *diverging* as they approach Q sufficing for the purpose. The telescope is used for reading only, and need not be clamped. It must, however, be quite firm so as not to shake the instrument.

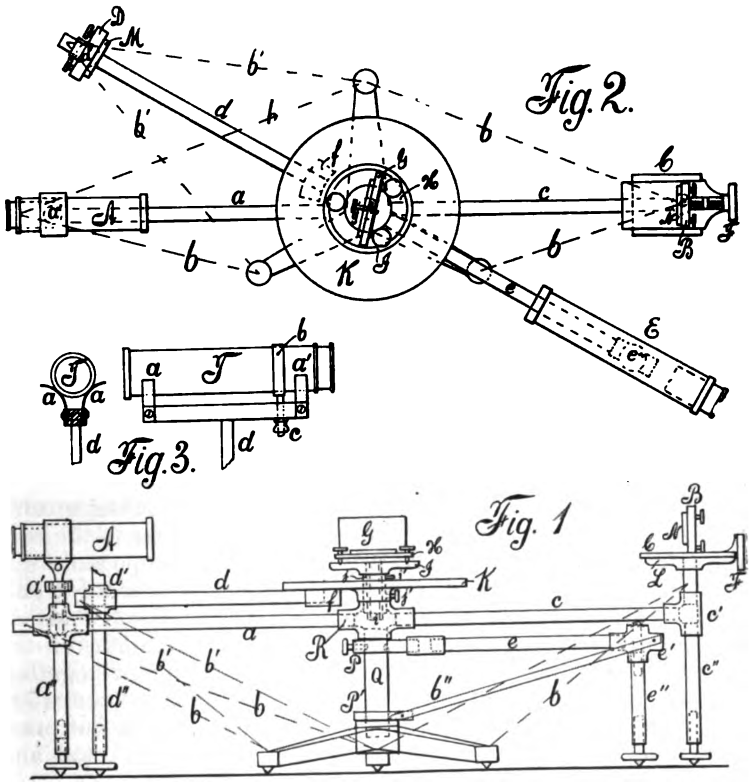
The standard Q is prolonged above the cross-coupling R as shown at *j* and the graduated plate at K (for measuring the angle of incidence I) rotates around Q prolonged. The plate may be clamped by the set screw j'. Radially to K, the lateral arm *d* is bolted below the plate at *f*. D carries the opaque mirror M, which thus rotates around Q with K.

The adjustment chosen is such that the parts M, N, G (the grating), the telescope E and the collimator A may be displaced upward several inches, in the clear. It is thus possible, for instance, to place the fog chamber between MG or NG.

The inside of j or Q prolonged is ground and receives the hollow cylindrical plug i of the table I and this may be clamped by the set screws i'.

Upon I stands the grating G secured by the screw g to the ring-shaped support H, which reposes in an annular gutter in I on three leveling screws. Moreover a spiral spring (not shown)

Figs. 1, 2, 3.



in the inside of the hollow conical tube i, pulls down the ring H firmly upon I, so that nothing is liable to fall on transportation. The ruled surface of the grating G is toward the light or collimator A and in the axis of rotation. The adjustment need not be very accurate. The rulings are parallel to the slit.

Certain details of the parts of the apparatus may now be pointed out. The collimator A may be raised or lowered on its vertical stem or clamped in any position by aid of the wing nut, a', on a longitudinally split tube. It may also be slightly

inclined to the horizontal, either by the hinge indicated in the figure, or by the special device shown in fig. 3, where the telescope or collimator reposes on Y's made of strips of elastic brass *aa*. These are so adjusted that the end of *T* at *a′* is naturally higher than at *a*. The ring *b* and the thumb screw *c* then lowers this end against the upward pressure of all the springs. Reading telescopes so mounted are firm and the device is very convenient if a slight inclination is to be imparted. They are removed by loosening *c*, and slipping *T* out of the ring, *b*.

The tube *a* ends on the left in the cross-coupling, which also admits the adjustable standard *a″* and affords an attachment for the braces *bb* (U-shaped in section), the other ends of which are bolted down to the nearer feet of the tripod. Thus *A* is held sufficiently rigid by the braced system *aa″ bb*. An inch or a 3/4 inch objective and a 6 inch focus is sufficient and by reason of its lightness perhaps preferable to a larger and heavier tube. The slit may usually be opened about $1/2^{mm}$.

In a similar way steadiness, elevation and inclination of the telescope *E* is secured, the tube *e* and *e″* (adjustable foot) and the braces *b″* terminating in the cross-coupling *e′* as has been suggested. An inch objective and a 6 inch focus is adequate. Cross hairs are convenient but not necessary, as the spectrum lines are available when sunlight is used. If the arc light is used, strong sodium lines are usually in the field with the spectrum.

The opaque mirror *M* is controlled by three leveling screws (horizontal and vertical axes) and a suitable spring in the capsule *D*. It is adjusted vertically like the telescope and kept firm by the tubes *d* and *d″* (adjustable foot) and braces *b′ b′*, all parts meeting at the cross-coupling *d′*. The braces *b′ b′* are of equal length. Hence they may be bolted down to two of the feet of the tripod in succession, while the tube *d* together with the plate *K* take the three positions at 30°, 90°, and 150° to the rod *a*. The grating *G* does not turn with *K* but must be specially adjusted to corresponding angles of 15°, 45°, and 75°, as easily determined by the reflected rays.

Finally the slide micrometer is sustained by the tubes *c* and *c″* (adjustable foot) and the braces *bb*, all parts meeting in the cross-coupling *c′*. The latter carries the table *L*, to which the slide micrometer *C*, with its drum at *F*, is bolted down. *N* is the opaque mirror adjusted by three leveling screws and a spring (horizontal and vertical axes) within the capsule *B*. The slide should have from 1 inch to 2 inches of clear play and its displacements should be determinable to about $\cdot 00005^{cm}$. The opaque mirrors *M* and *N* may both be silvered on the back and thus last indefinitely.

Since the telescope E rotates both around its own axis e'' and around the standard Q, elaborate centering of the grating G is not usually necessary. The latter is mounted between strips of cardboard or wood and secured by the screw g, the brass clutches being about twice as far apart as the thickness of the grating. In other words, the grating may be slightly moved in a direction normal to itself.

To adjust the parts, sunlight (preferably) or arc light is passed into the widened slit of the collimator, in a dark room, so that the spots falling on the mirrors M and N (the grating being suitably turned) and on the objective of the telescope E are seen and the different reflected images brought nearly into coincidence. A further adjustment is then made through the telescope E, two of the usual four images of the slit (now narrowed) being placed in coincidence horizontally and vertically by manipulating the leveling screws on B. Specks of dust, or nicks in the slit, greatly facilitate this adjustment. The telescope is then turned to the diffraction spectrum, preferably of the first order, and the drum actuated till the interferences appear. Naturally the distances GN and GM are to be approximately equal to begin with. The solitary ellipses are best for general purposes and they usually correspond to undeviated yellowish and bluish single slit images. The multiple slit image is to be avoided. If the rings are not quite centered in the spectrum, they may be made so by cautiously adjusting the screws at B, which tip the mirror about a horizontal axis. The telescope may be moved with its foot sliding on a plane. The three possible positions of the mirror N (positive uncompensated, self-compensated, negatively uncompensated) are about 1^{cm} apart on the micrometer, for a plate of glass $\cdot 68^{cm}$ thick. When the arc lamp is used, the accentuated sodium lines in the spectrum may be used in place of the white undeviated images of the slit, both for adjustment of the two spectra for coincidence and as a fiducial mark, in place of the cross hairs in the telescope. For a small angle of incidence the sodium lines of higher orders of spectra are also liable to be available.

To measure the angle of incidence I, the table I is turned in its socket, until the reflected image of the slit coincides with the slit itself. A hole is cut in the top or side of the collimator tube near the slit (not shown), for this purpose. Thereupon the table I is turned back again until the images coincide in the telescope. The angle read off on the graduated plate K is I, the reflected ray travelling over $2I$. The table I is provided with an index and vernier (also omitted in the diagram).

The apparatus described being made virtually of hollow parts is light enough to be carried about with convenience.

In the case of the figure where the angle of incidence I is small, the distance from M to N is about 70^{cm}. It may easily be increased to several times this, by inserting longer gas pipes at c and d with appropriate braces. The fringes are very stable even when the instrument stands on a table fastened to a wall bracket. They naturally quiver when the observer is manipulating the micrometer screw, but they return at once to quiescence when the hands are removed. To obviate quivering, i. e. to follow the motion of individual rings, the usual tangent screw method may be employed.

2. *Other Interferences.*—The same apparatus may be adapted for observing the linear diffraction-reflection interferences described by Mr. M. Barus and myself.* The equations here available are

$$\delta e = \lambda / 2 \cos i \,; \;\; \delta e' = \lambda / 2 \cos \theta \,; \;\; \delta e'' = \lambda / 2 \, (\cos \theta - \cos i)$$

where δe, $\delta e'$ and $\delta e''$ are the respective increments of the air spaces between the face (rulings) of the grating and the parallel opaque mirror in front of it, per fringe passing the cross hairs of the telescope, or a given spectrum line, λ the wave length of light and i and θ the angles of incidence and diffraction in air. For the measurement of δe, λ, i, θ should be known or determinable.

For these observations let the micrometer C be removed from its plate L and now bolted down on the graduated plate K (figs. 1, 2), the table I and appurtenances being discarded. This must be so done that the face of the opaque mirror N now mounted on the rigid part of the micrometer and the rulings of the grating (remounted on the slide of the micrometer) are in the axis of rotation, with the lines of the grating parallel to it and the slit. Hence the mirror must be adjustable by aid of a capsule with set screws (horizontal and vertical axes of rotation) and springs. The grating has its independent mounting with three similar set screws and springs. Usually N will be attached to some apparatus whose linear excursions are to be found, and for this purpose of attachment the cross-coupling R in fig. 1 is abundantly supplied with screw sockets (front and rear, not shown), so that such parts may be here secured. A counterpoise, for instance, may be added in the rear.

To prepare for observation, the plate K and the telescope E are turned until a suitable angle of incidence i and of diffraction θ are obtained. The fringes are seen when grating and mirror are sufficiently near together (the distance apart may be as much as 1^{cm}), on condition that the direct images of the slit

* The grating interferometer. Science, xxxi, 394, 1910; Phil. Mag. (6), xx, p. 45, 1910; Carnegie Publications, No. 149, chap. 2, 1911.

from the front face of mirror and the rear face of grating are in coincidence horizontally and vertically. E may be revolved for this preliminary adjustment. To find the angle of incidence, the graduated plate K is turned from the given position of coincidence until the image of the slit falls upon the slit itself at the end of the collimator A, as explained above. If the fringes are not sharp, they may be made so by further adjusting the set screws of N or the grating, by trial. This usually succeeds easily, remembering that the fringes move about a horizontal axis normal to the mirror when the mirror moves about a horizontal axis parallel to its face. For other details the earlier paper should be consulted.

15. *Other Measurements: High Temperature, Adiabatic Transformations, etc.*—The displacement interferometer constructed with its arms made of gas pipe is adapted for high temperature investigation, if a current of cold water, at constant temperature, be passed through the arms in question; they will then be kept at invariable length, however much the atmosphere about them may change in temperature. Furthermore, since the distance between the central grating and the opaque mirror may easily be increased to a meter or more, tubes of considerable length may be inserted in the interfering beams of light. The displacement interferometer should be used with the angle of incidence nearly zero, in which case this angle vanishes from the micrometer reading and the observing telescope lies in a particularly convenient position side by side with the opaque mirror on the micrometer. This is thus immediately at hand.

It seemed to me, therefore, that a particularly interesting subject for investigation would be the relation of temperature and pressure of the index of refraction μ of air. According to Lorentz* the $\mu-1$ for air follows the equation

$$p = C(\mu-1)\delta$$

(p pressure, C constant, δ absolute temperature), coinciding in form to the intrinsic equation of a gas since the temperature coefficient of $\mu-1$ for air is very nearly equal to its coefficient of expansion. Mascart finds this not quite true. Pressures are to be corrected by $(1+\beta p)$ where β is equal to ·000,007,2 relative to cm. of mercury and the temperature coefficient is a = ·00382. At all events, the temperature coefficient a is so large that a method of high temperature measurement is not out of the question on the one hand, while on the other the variation of a throughout long ranges of temperature is itself of considerable interest. I have, therefore, made a few tentative measurements at low temperatures to test the apparatus

* See the admirable summary in Landolt and Boernstein's Tables.

and have found it trustworthy throughout. In the following table the apparatus is adjusted with an angle of incidence of $I=15°$. The index of refraction is determined from the displacement of ellipses when the air contained in a longitudinal sealed tube in one of the component beams of light which interfere is alternately filled with air at pressure p and exhausted, at a given temperature t. This tube was $23{\cdot}8^{cm}$ long and of brass, surrounded with a close fitting tubular temperature bath.

TABLE I.—Index of Refraction of Air from shift ΔN of ellipses. $e=23{\cdot}8^{cm}$. Angle of incidence $I=15°$.

Barometer cm.	Vacuum cm.	Shift (scale pts.)	Shift ΔN cm.	μ	t
76·95 19°	·5	13·27	·00663	1·000279	30°?
76·98 24°	·4	13·48	·00674	1·000283	23°
77·15 21°	·4	14·54	·00727	1·000306	2°
77·15 21°	·4	13·55	·00677	1·000284	21°

The first two columns of the table show the barometric height and degree of exhaustion (residual pressure); the third the micrometer displacement of the opaque mirror which brings the centers of ellipses back to their original position with reference to a given spectrum line. This reading is taken on the drum on the micrometer, the scale parts being $\cdot 0005^{cm}$. When electric arc light is used, the accentuated sodium line is always in presence in the spectrum and makes an excellent fiducial line for the centers of the ellipses. A single exhaustion is sufficient for two readings, as the displacement occurs on exhaustion (from red to green, for instance) and is measured by the turn of the micrometer to bring the ellipses back; while on readmitting air the displacement is in the opposed direction and is again measured by restoring the center of ellipses to the position of the sodium line. If this displacement of the opaque mirror on the micrometer is ΔN cm. the index required is

$$\mu = 1 + \Delta N/e$$

if e is the length of the tube. ΔN must be given in cm. as shown in the fourth column of the table and from this the μ of the fifth is found at the temperature t in the last column. They refer to the wave length of the D line, as this was taken as the fiducial mark. The absolute values of μ are good but here of relatively little interest, as no attempt was made to standardize the screw, etc. of the measuring apparatus, and the

water circulation had not been installed. The temperature coefficient may be found without this. If, therefore, $\mu-1$ is expressed in terms of t the result is $a=\cdot 0036$, or of the order expected.

From this datum the working conditions of the apparatus may be specified. For a tube $23\cdot 8^{cm}$ long the micrometer displacement per degree $C.$ is ·051 scale parts or $\cdot 0005^{cm}$ each; i. e., the micrometer displacement is about $\cdot 000{,}025^{cm}$ per degree $C.$, or about $10^{-6\,cm}$ per degree $C.$ per cm. of length of tube. Thus a minimum of about 2° $C.$ is directly appreciable in the given case, or for a tube about half a meter long a minimum of 1° $C.$ should be appreciable at all temperatures. This moreover would correspond to the evanescence of two rings in succession, whereas in the above apparatus a little less than one ring vanishes per degree $C.$, at all temperatures. The displacement of ellipses for an atmosphere of pressure is roughly from the D, nearly to the E line.

In this method the arms need not be of invariable length except during the short period of exhaustion, as the data are obtained by differences.

To turn to the second method for obtaining the same result: the displacement of ellipses is accompanied by the radial motion of rings to and from the center and the number vanishing may be counted. If λ is the mean wave length between the initial and final position of the rings and n is the number of rings vanishing, then the equivalent micrometer displacement would be

$$\Delta N = n\lambda/2$$

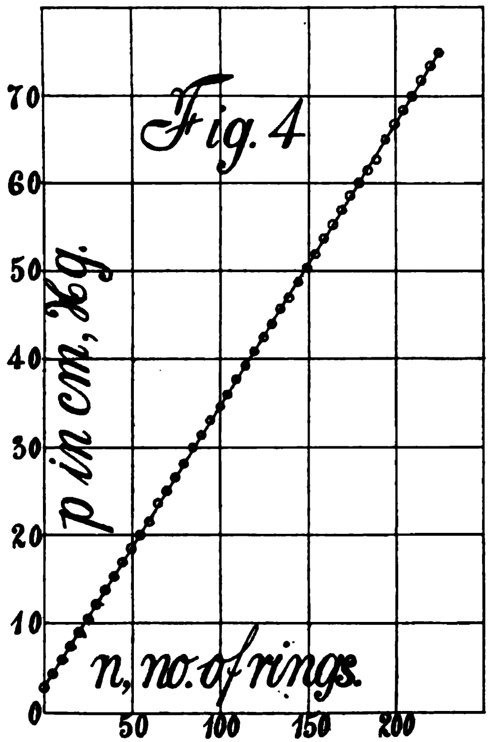
so that the micrometer reading ΔN need not be taken. Hence

$$\mu = 1 + n\lambda/2e$$

To make use of the method, a fine screw stopcock is to be inserted through which dry air may be admitted, at any rate, into the exhausted tube. In this way the motion of the rings toward the center may be controlled, perfectly, and their evanescence specified. The experiment is very interesting. Clearly the arms must be kept at invariable length while the rings are being counted, i. e., until they cease to move, when the pressure is against normal. The following figure contains an example of many results of this kind. Here the abscissas denote the number of rings which have vanished and the ordinates the corresponding pressure, the latter increasing from a few mm. to an atmosphere. The line of observations happens to be nearly continuous. An interruption of the count is, however, of no serious consequence, as the slope of the line is alone in question when the initial pressure and final pressure

are known. It is surprising to note how closely these observations lie on a straight line. They do so quite within the errors of observation.

Fig. 4.



The slope of the line is

$$\frac{70{\cdot}0-2{\cdot}8}{210} = {\cdot}320$$

i. e., $\cdot 32^{\mathrm{cm}}$ of mercury at 0° *C.*, per ring vanishing; or, a little over 3 rings (3·125) per cm. of mercury. The mean wave length in question (between the *D* and *E* line) is about $\lambda = 55{\cdot}8 \times 10^{-6}$. Hence, as the effective barometer was $76{\cdot}95^{\mathrm{cm}} - {\cdot}50 = 76{\cdot}45^{\mathrm{cm}}$ and the tube length $23{\cdot}8^{\mathrm{cm}}$.

$$\mu = 1 + \frac{76{\cdot}45 \times 27{\cdot}9 \times 10^{-6}}{{\cdot}32 \times 23{\cdot}8} = 1{\cdot}0002806$$

The datum obtained from the displacement of ellipses at the same temperature (unfortunately not taken) was 1·000279.

Inasmuch as the water circulation was omitted during the ring measurements and the exact value of λ was not specially found, the agreement is as close as may be expected.

The two data selected from many similar results show how easily both methods may be used for mutual corroboration. Clearly the ring method, since it involves the evanescence of 236 rings, is more sensitive, but also less expeditious. It is not, however, necessary to observe all the rings; the disappearance of a reasonable number, say 25 or 50, establishes the rate of evanescence per cm. of mercury, or more conveniently the number of cm. of mercury per vanishing ring. If this is determined at the beginning and end of exhaustion the mean result is adequate.

If the air tube of the apparatus is so modified that the air may be heated electrically the ring method should be equally available for temperature measurements. The results could be compared with a thermo-couple having its fine junction inserted in the tube and read simultaneously.

As a method of *pressure* measurement, since for a tube $23{\cdot}8^{cm}$ long, 3·12 rings vanish per cm. of mercury, i. e., about ·1313 rings per cm. of tube length per cm. of mercury pressure, the method is not very sensitive unless a long tube be used. A tube 1 meter long would, for instance, give 13 rings per cm. of mercury, admitting of the measurement of pressure to $\cdot 08^{cm}$ per ring. One might estimate to $\cdot 5^{cm}$, while a more highly refracting gas would secure greater precision.

The method of pressure measurement has the rare advantage, however, of being absolutely instantaneous, as reproducing immediately the state of the gas. It is therefore remarkably well adapted for the study of adiabatic phenomena. Many equations relatively to such transformation of gases are thus open to investigation. Since $(\mu-1) = \Delta N/e = n\lambda/2e$ and $p = C(\mu-1)\,\delta$,

$$\frac{p}{\delta} = C.\,\Delta N/e = C\lambda n/2e,$$

the variations of p/δ are directly given by the number, n, of rings vanishing. But the relation of p and δ is also given either by the intrinsic equation of the gas or by its adiabatic equation, according to the transformation which has been imposed on the gas, so that p and δ are each determinable.

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Art. XVII.—*The Unconformity at the Base of the Chattanooga Shale in Kentucky;** by Edward M. Kindle.

Introduction.—It is proposed to describe in this paper the physical evidences of the unconformity which exists at the base of the Chattanooga shale in Kentucky. This unconformity occurs in a region of horizontal or but slightly inclined rocks, so that there is no discordance of the strata involved to render it conspicuous or easily detected. For this reason, perhaps, physical evidence of it appears to have been generally overlooked by the authors of State and Federal reports on the geology of the region. Professor Foerste and others, however, in various papers on the geology of Kentucky, have evidently inferred an unconformity at the base of the shale on the evidence of missing faunas at its base.

A photograph and description of the contact of the Chattanooga shale and Devonian limestone in middle Tennessee has been published by Professor Schuchert† to illustrate the complete absence of evidence of unconformity between the two formations, aside from the age of their faunas, and our dependence upon the discordance in the superposed faunas for our knowledge of the hiatus between them.

In eastern Tennessee an unconformity at the base of the Chattanooga has been reported in several of the folios.‡

The writer § has previously called attention to the evidence of an erosion interval at the base of the shale at one or two points on the western side of the Cincinnati geanticline. But the widely distributed evidence of land conditions and a considerable amount of subaerial erosion immediately preceding the deposition of the Chattanooga shale interval, if recognized in Kentucky by any geologist, has thus far remained unrecorded.

The photographs which accompany this paper (figs. 2 and 3) make it sufficiently clear that physical evidence of the most unequivocal kind is available to supplement the evidence of unconformity furnished by the faunas. Such evidence in connection with faunal breaks substitutes a known for an unknown factor in problems where a hiatus is involved. If this factor of the geologic equation is left for deductive resolution from the faunal factors alone, it may turn out very differently in the

* Published with the permission of the Director of the U. S. Geological Survey.

† Paleogeography of North America, Bull. Geol. Soc. America, vol. xx, p. 441, pl. 47, 1910.

‡ Knoxville, Loudon, Maynardsville, Morristown, and Columbia Folios, U. S. Geol. Survey.

§ Williams, H. S., and Kindle, E. M., Contributions to Devonian Paleontology, 1903, Bull. U. S. Geol. Survey, No. 244, pp. 20–21, 1905.

hands of different men. Through the deductive method based on the faunas alone one geologist may find in the total absence of a fauna or faunas evidence of land conditions during the interval represented by the missing fauna; another with different predilections may interpret this absence, if no evidence of subaerial erosion has been adduced, to marine scour or temporary suspension of sedimentation without land conditions. Geologists agree that unconformities mark important datum planes in stratigraphic geology. Hence the evidence for them is of sufficient importance to warrant full and complete presentation from both the biological and physical points of view.

In this particular case the faunal evidence affords sufficient proof of unconformity independent of physical evidence, but in various other cases unconformities have been introduced by geologists where theoretic considerations regarding supposed diastrophic movements appeared to require their presence. An example of this kind of unconformity is one recently placed within the New Albany shale* of Indiana (Chattanooga) without a vestige of direct evidence in support of it. The history of such an unconformity as this hypothetical one within the New Albany is likely to be similar to that of the unconformity which was drawn at the top of the Chattanooga in central Tennessee some years ago by Hayes and Ulrich.† In a recent paper by the last named author‡ this unconformity is abandoned without any explanation of the nature of the defects in the original evidence. It appears to have migrated to the top of the next formation above the Chattanooga, designated by Ulrich the Ridgetop. Whatever the ultimate verdict regarding the unconformity at the top of the Chattanooga shale may be, the following discussion will show that the unconformity at the base of this formation does not belong to the evanescent class of unconformities.

Distribution of the Chattanooga Shale.—The Chattanooga shale, briefly characterized, is a formation composed chiefly of black fissile carbonaceous shale ranging from about 240 feet in the northern part of the state to 25 feet in the southern part. The areal distribution of the Chattanooga shale as an outcropping formation in Kentucky is confined to two geographically separable areas. By far the larger and more important of these is the narrow semicircular band which borders the dome of Ordovician and Silurian rocks in Northern Kentucky on the east, south, and west. From Vanceburg on the east to Louisville on the west the Chattanooga shale extends around the

* Ulrich, E. O., Revision of the Paleozoic System, Bull. Geol. Soc. America, vol. xxii, pl. 28, 1911.
† Folio U. S. Geol. Survey, No. 95, 1903.
‡ Bull. Geol. Soc. America, vol. xxii, pl. 29, 1911.

dome of older rocks in a broadly crescent-shaped belt having a zigzag line of outcrop more than 250 miles in length. Separated from this area by a narrow belt of Carboniferous rocks is the valley of the Cumberland River in southern Kentucky. The black shale extends up this valley from Tennessee about 50 miles. It is probable that this formation extends without interruption across the entire state beneath the younger rocks outside the above described areas in which strata older than the Chattanooga shale are the surface rocks.

Description of unconformity.—A large number of outcrops showing the contact of the Chattanooga shale and older rocks, which are widely distributed along the lines of exposure of the shale as outlined above, have been studied by the writer. In nearly every district visited physical evidences of an erosion interval have been observed. These evidences may be referred to three classes, namely: (1) irregular or mammillary surface of the subjacent limestone, (2) beds of residuary clay beneath the shale, and (3) deeply excavated trenches and shale-filled cavities of solution in the underlying limestone. The first and second named phenomena have a wide distribution, but the third, as might be expected, is found rather rarely. In localties where the limestone base of the black shale has been recently denuded of the shale, one very frequently finds the surface of the limestone hollowed and pitted in the peculiar, irregular, and often angular manner similar to that which may be seen at nearly any limestone quarry where the rock has been stripped of its residuary clay. A good example of this hummocky surface on the Devonian limestone where the shale has been recently removed occurs southeast of Crab Orchard, Kentucky, 1½ miles on the Gum Sulphur road. Near the schoolhouse at this locality the highly uneven hummocky surface of the limestone can be traced directly under a 10-inch bed of reddish brown clay which separates the black shale from the weather-worn limestone below. Here one sees in the vertical cross-section of the limestone beneath the shale the angular ridges, truncated cones, and mammillary protuberances covered with a clay which differs from the usual residuary limestone clay only in being of a duller color. The correspondence in appearance between the surface of this irregularly worn limestone and that usually seen in limestones recently denuded of their clay covering is complete and unmistakable. Numerous examples of subaerial erosion of this kind have been observed around the fringe of Chattanooga shale which circles the older rocks south of the Ohio. On the west side of the Cincinnati geanticline, south of the Ohio river 15 miles, evidences of the pre-Chattanooga erosion interval are apparent near Brooks station. In the bed of Brooks Run, between the railroad and

the wagon road, the lowest strata of the black shale lie in shallow, irregularly eroded pockets in the limestone. In some of these a thin layer of reddish clay was observed between the limestone and the undisturbed black shale.

In the southwestern part of the black shale area of outcrop near Rileys station in Marion county, unconformity at the base of the shale is well exposed in a small ravine a few hundred yards northwest of the railroad station. Here the hollows in the limestone under the black shale are deeply filled with dull red residuary clay, while but a thin band of the clay covers the intervening elevated ridges in the limestone. The upper surface of the latter is extremely uneven and seldom conforms with the approximately parallel bedding planes in the limestone. The unconformity as it is seen here is illustrated by

Fig. 1.

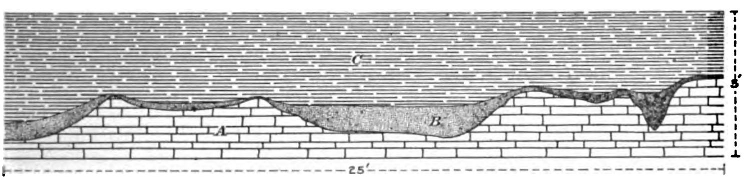


Fig. 1. Section at Rileys, Kentucky, showing irregular surface of Devonian limestone and residuary clay beneath the Chattanooga shale. *A* Devonian limestone, *B* residuary clay, *C* Chattanooga shale.

fig. 1. The maximum thickness of the residuary clay which has been observed at the base of the black shale occurs in Madison County, southwest of Berea, near the head of the west fork of Rocky Branch. The clay has a thickness in places of 3 feet or more at this locality. It is a brown clay containing numerous fragments of the chert which characterizes the underlying Devonian limestone on Rocky Branch. The clay lies at this locality in deeply excavated troughs and pot-like depressions in the limestone. The upper part of this clay shows indications of having been reworked. One or more thin papery bands of shale show a superposed bed of clay.

The place usually occupied by the residuary clay which has been described is sometimes filled on the eastern side of the Cincinnati geanticline by a limonite ore. The iron ore has been found in the form of small lenticular and widely separated masses over a line of outcrop nearly 150 miles in length, extending through Boyle, Lincoln, Montgomery, and Casey counties as far north as Peebles, Ohio. This ore was extensively worked at one time near Preston, Ky., where the bed is said to have had a thickness of from 7 to 15 feet.

The most striking examples of pre-Chattanooga erosion in the Devonian limestone which have been observed occur at Irvine, Ky. A considerable exposure along the railway west of town shows the contact of the Chattanooga shale and the Devonian limestone to be, as it often is, a horizontal line with no intervening residuary clay and no departure from exact parallelism of the adjacent formations. Foerste* has published photographs illustrating this type of the contact elsewhere in Kentucky. Near town, however, this apparent

FIG. 2.

FIG. 2. Chattanooga shale and Devonian limestone unconformity at Irvine, Kentucky. The Chattanooga shale is marked *A*, and the Devonian limestone *B*.

conformity of the two formations terminates abruptly, and we find the black shale resting for several yards on a highly irregular surface of the Devonian limestone, and on one side of the section abutting against a vertical wall of limestone about 8 feet in height. The general relations of the two formations at this point are shown in the photograph fig. 2. The beds marked A are a nearly pure limestone of Onondaga age. Those marked B are the basal beds of the Chattanooga shale, which at this horizon includes some dark magnesian and silicious beds interbedded with black shale. In the illustration the hammer rests upon the side of the limestone ledge and the hand of the man upon the shale. The details of this vertical contact

* Kentucky Geol. Surv. Bull. No. 7, figs. 8, 9, 1906.

are shown more clearly in fig. 3, in which the hammer rests with one end against the shale and the other against the limestone. Fig. 3 also shows more clearly than fig. 2 the walls of a small water-worn cavity in the lower half of the ledge

FIG. 3.

FIG. 3. Close view of a portion of the black shale and limestone contact line shown in fig. 2. A solution cavity in the limestone filled with black shale is seen under the hat. The shale is marked *A*, and the limestone *B*.

which extends nearly, if not quite, to the bottom of the limestone. This cavity, filled with a deposit of the black shale, is

seen in the photograph just above the bag. The hat rests upon the upper part of the filling of the Chattanooga shale. Since the Devonian limestone in the vicinity of Irvine seldom exceeds 10 feet in thickness, it is evident from the photographs that it was locally almost, if not entirely, cut through by subaerial erosion previous to Chattanooga sedimentation. Another exposure of the contact of the two formations which occurs in the small ravine between the town and the station at Irvine shows a still more advanced stage of denudation of the limestone than that illustrated in the photographs. Here the Devonian limestone has been reduced to large disassociated bowlders. These have been enveloped by the Chattanooga shale, which lies upon and around them and rests directly on the subjacent Silurian shale between the bowlders.

The significance of the remarkable and apparently haphazard variations in the thickness of the Devonian limestone in east central Kentucky to which Foerste* has called attention, becomes evident in the light of the preceding examples of subaerial erosion of this formation subsequent to Chattanooga shale deposition. These variations in thickness range from a few inches to 47 feet according to Foerste. The following striking cases are quoted from Professor Foerste's report: †

"Another thick section of Devonian limestone occurs three miles southwest of Cartersville, where the road to Crab Orchard crosses the headwaters of Harmon creek. Here the Devonian limestone is seventeen feet thick. Half way between this locality and Crab Orchard the thickness of the Devonian limestone is only six feet, so that the Devonian limestone appears to become thinner from both areas toward this middle region. . . . Directly north of Berea the thickness of the Devonian section is thirteen and a half feet. Four miles north of Berea it is reduced to three inches. Evidences of thinning are seen also in going from Berea northeast, toward Bobtown. In the vicinity of Bobtown, and from this region for at least three miles toward the east and northeast, the thickness of the Devonian limestone is reduced to about one foot or less, except at the Mat Moody Store, a mile and a quarter toward the southeast of Bobtown. Here the thickness of the Devonian limestone is at least four feet four inches, again suggesting an irregular thinning of the Devonian limestone toward the north."

It would seem to be a reasonable inference that the subaerial erosion which rendered the Devonian limestone cavernous and in places reduced it to a bed of bowlders as at Irvine, may, where the pre-Chattanooga relief was greater, or the drainage more

* The Silurian, Devonian, and Irvine formations of East-Central Kentucky, Kentucky Geol. Survey, Bull. No. 7, p. 89–92, 1906.

† Idem., p. 90.

deeply incised, have removed it altogether. The very irregular and patchy distribution of the Devonian limestone which obtains in southern Kentucky and adjacent parts of Tennessee, taken in connection with the evidences of its partial erosion in central and northern Kentucky, strongly suggests that this formation has been completely removed over a considerable area near the Kentucky-Tennessee line and over smaller areas in central Kentucky. In the latter area the Devonian limestone is generally present where the Chattanooga shale is found, but over certain areas, as the regions between Bardstown and New Haven, between Raywick and Loretta, and south of Stanford, it is entirely absent. Farther south it is not the absence but the presence of the Devonian limestone which is exceptional. Southwest of the southern limit of the Devonian limestone in Kentucky, as indicated on Foerste's† map, a detached area of this formation occurs on the Rolling Fork River. The writer has found another on the Green River near Edith P. O. A third occurs south of the Tennessee line on the Harpeth River. In the light of the evidence which has been presented of the extensive denudation of the Devonian limestone at Irvine, it appears nearly certain that these outlying patches of limestone are remnants of a once continuous sheet of Devonian limestone. Its relatively greater degree of denudation is doubtless the result of the greater elevation of the axis of the Cincinnati geanticline in southern Kentucky and northern Tennessee.

Time interval represented.—Any conclusion concerning the time interval represented by the unconformity which has been described must rest upon the determination of the age of the formations involved. The complexity of this question is apparent when we consider that the unconformity involves at its base at least six distinct formations in Kentucky ranging in age from Ordovician to Middle Devonian. This, of course, raises the question whether in one part of the area land conditions began as early as Ordovician and in another part as late as post-Hamilton time, or whether differential erosion is responsible for the difference in age. The evidence already given of the nearly complete denudation of the Devonian limestone by subaerial erosion at one locality seems to strongly support the probability that the absence of the later formations in part of the Kentucky area is due to denudation rather than to land conditions having persisted in certain areas from Ordovician to the beginning of Chattanooga sedimentation. Obviously the question of transgression or overlap comes into the problem. But we have to discover whether the transgression proceeded rapidly and at approximately the same rate from all sides, or

* Silurian and Devonian limestones of Tennessee and Kentucky, Bull. Geol. Soc. America, vol. xii, fig. 8, 1901.

whether it proceeded very slowly and chiefly in the direction of the oldest rocks exposed at the base of the unconformity. The latter view seems to have been maintained by some geologists as a corollary of the dogma of very slight erosion of Silurian and Devonian lands. The photographs and other evidence here presented indicate the necessity of very materially modifying this assumption. It is of course possible to have had a southerly transgression of the black shale across Kentucky at the close of such a cycle of erosion as has been indicated in this paper, but proof of this must rest on evidence of distinctly different age values of the basal faunas of the black shale at the north and at the south. It is desirable here to ascertain just what evidence there is, if any, for such differences in the age of the shale. Prof. Edward Orton, Jr.,* appears to have been one of the first to claim that the black shale in Kentucky represented only the "Upper or Cleveland Division" of the Ohio shale. His statement is as follows: "The shale that covers the Lower Silurian limestone in central Kentucky is the Upper or Cleveland Division." This opinion concerning the age of the Chattanooga shale is comparable to some which have followed it in the poverty of evidence on which it rests and the positive phrasing which might mislead one unfamiliar with the subject to suppose that it represents an established fact.

No complete or entirely adequate discussion of the time interval represented by the unconformity at the base of the Chattanooga shale can be given until the fauna and stratigraphy of this formation have been described in detail. Although generally considered to be nearly barren of organic remains, the writer has found the carbonaceous beds of the Chattanooga shale to carry a conodont fauna which is quite as abundant in the lower or Huron shale of Ohio and Kentucky as it is in the upper or Cleveland shale. These minute but beautifully preserved fossils may be obtained at any locality and at any horizon in the black shales from Lake Erie to Alabama. These fossils have long been known in Ohio in the upper beds of the Ohio shale, but with the exception of a very few species have remained undetermined and undescribed. When they have been described and the species which are confined to the upper and lower horizons of the shale distinguished, they will prove an invaluable aid in correlating the different parts of the Ohio shale in Ohio with their equivalents in the Chattanooga shale in Kentucky and farther south. Until this has been done, however, any attempt to make use of these fossils in correlating subdivisions of the Ohio and Chattanooga shale must be considered premature and futile. Hence, in the present discussion of the age of the interval represented by the

* Geol. Survey of Ohio, vol. vii, p. 23, 1893.

unconformity at the base of the Chattanooga shale, the previously adduced evidence of the age of the shale will be considered chiefly.

Devonian fossils have been found by various geologists in the lower part of the Chattanooga shale in Kentucky and in its equivalent, the new Albany shale, in Indiana. For a summary of the literature relating to the Devonian age of the Ohio shale which has appeared previous to 1898, the reader is referred to Dr. George H. Girty's* important contribution to the age of the Chattanooga shale in eastern Kentucky. Somewhat later the writer† published a short list of Devonian fossils obtained from the Chattanooga shale on the western side of the Cincinnati geanticline. The whole of the Chattanooga shale was generally considered to be of Genesee age until Prof. H. S. Williams‡ reported that Carboniferous fossils appeared in the topmost beds of the formation at Irvine. The excellent stratigraphic work done by Foerste and Morse§ in northern Kentucky has shown that these Carboniferous fossils at Irvine occur in beds which are the southern extensions of the Berea, Bedford, and Sunbury formations of southern Ohio. They have shown that about 4 feet of the uppermost beds previously included in the 150 feet of the Ohio or Chattanooga shale in east central Kentucky are the stratigraphic equivalents of beds which in northern Ohio immediately follow the Ohio shale and have a total thickness of about 150 feet. The thinning of these beds in crossing southern Ohio and northern Kentucky, though very marked, harmonizes fully with the attenuation which the Ohio shale suffers in being reduced from a thickness of more than 2400 feet east of Cleveland to less than 150 feet at Irvine, Kentucky.

On the basis of diastrophism Grabau,‖ Schuchert,¶ and Ulrich** have referred the Chattanooga shale in Tennessee to the Mississippian. These authors, though differing widely as to the direction of movement of the transgression, agree in assuming that it culminated in the deposition of the Chattanooga shale in Mississippian time. Concerning this correlation and the method by which it was derived, it is perhaps sufficient to quote Professor Schuchert's remarks on the diastrophic method. He states:

* Description of a Devonian fauna found in the Devonian black shale of eastern Kentucky, this Journal, vol. vi, p. 385, 1898.

† Bull. U. S. Geol. Survey, No. 244, p. 20, 1905.

‡ This Journal, vol. iii, p. 398, 1897.

§ Jour. of Geology, vol. xvii, pp. 164–167, 1909.

‖ Types of Sedimentary Overlap, Bull. Geol. Soc. America, vol. xvii, pp. 599–701, 1906.

¶ Paleogeography of North America, Bull. Geol. Soc America, vol. xx, p. 441, 1910.

** Revision of the Paleozoic Systems, Bull. Geol. Soc. America, vol. xxii, No. 3, p. 307, pl. 29, 1911.

"In fact, the principle of diastrophism can rarely be used before taking the fossil evidence into account, for it is the latter that fixes and determines physical events. Diastrophism, however, is of much value in paleontography, but it must follow, not precede, the evidence furnished by the fossils."

None of these authors has given us any faunal evidence for transferring the Chattanooga shale to the Carboniferous from the Devonian, where it had been generally placed and to which it had previously been referred by one of them,* and separated from the Carboniferous by an unconformity.† Probably all of the paleontologic evidence which the advocates of the Carboniferous age of the Chattanooga shale might claim to support their view has been presented by Dr. R. S. Bassler.‡ Although his paper does not eschew diastrophism, it proceeds mainly on the paleontologic basis and consequently invites our careful consideration and critical examination. The contentions which Bassler makes in his paper are reducible to three distinct theses, which may be stated thus: (1) The Chattanooga shale of central Tennessee is a distinct formation from the Chattanooga shale of the U. S. Geological Survey folios of eastern Tennessee. (2) The Chattanooga shale should be correlated with the Cleveland shale of Ohio. (3) The Cleveland shale of Ohio is of Waverlyan age.§ Inasmuch as Dr. Bassler admits the Devonian age of the east Tennessee black shale, it is evident that the first proposition is of primary importance to his argument. It is stated by Bassler as follows: "East and northeast of this Chattanooga band of outcrop a similar black shale, but of undoubted Devonian age, has been mapped as the Chattanooga shale."¶ In support of the distinctness of the eastern and central Tennessee Chattanooga shale I find in Dr. Bassler's paper no evidence adduced beyond the reference of the central Tennessee Chattanooga to the Carboniferous. This reference rests primarily on evidence submitted by Newberry nearly forty years ago, the validity of which I am compelled to deny for reasons to be shown presently. During the past summer the writer has discovered in the most easterly outcrops of the Chattanooga shale in

* Ulrich, E. O., Prof. Paper, U. S. Geol. Survey, No. 36, p. 25, and Folio U. S. G. S. No. 95.

† Hayes, C. W., and Ulrich, E. O., Folio U. S. Geol. Survey, No. 95, 1903.

‡ The Waverlyan Period of Tennessee, Proc. U. S. Nat. Museum. vol. xli, pp. 209-224, 1911.

§ *Note.*—In another paper‖ the whole of the Ohio shale in Ohio has been referred to the Mississippian by Dr. Bassler. This reference, however, was evidently an oversight as regards the lower division of the Ohio shale, since no evidence has ever been offered by Bassler or any one else tending to prove that the lower portion of the Ohio shale is of later age than Devonian. So we may confine our discussion of the proposed revision to the evidence relating to the position of the Cleveland and Chattanooga shales.

‖ This Journal, vol. xxxi, p. 20, 1911.

¶ Idem, p. 215.

Tennessee the same conodont fauna which characterizes this formation at Chattanooga, the type locality. In view of this discovery of the same fauna on both sides of the barrier, which some geologists have assumed to separate the black shale of eastern and middle Tennessee, the claim of the distinctness of the shale in the two areas appears to be no longer tenable Since the Devonian age of the east Tennessee black shale has already been conceded, the finding of a conodont fauna which shows the essential faunal unity of the shale in both areas carries with it the evidence of the Devonian age of both.

With the second proposition the writer does not take issue except to state that it is probable that the Chattanooga shale in Tennessee will be shown to be the equivalent, not only of the Cleveland shale, but of much of the remainder of the Ohio shale as well.

With the third proposition I am compelled to disagree. Dr. Bassler does not claim to present any new evidence for referring the Cleveland shale to the Carboniferous but briefly restates* the evidence which led Newberry to refer these beds to the Waverly in 1874. It seems probable that Bassler was not aware of the excellent reasons which have led the authors of the official reports of the Ohio Survey since Professor Newberry's time to discard the evidence brought forward by Newberry and place the Cleveland shale in the Devonian. In the space here available it is only possible to refer briefly to the stratigraphic mistakes made by Newberry which must throw grave doubt upon any evidence which he presented for the Carboniferous age of the Cleveland shale. Prof. Prosser† has fully discussed some of these in his paper on the Sunbury shale, to which the reader is referred. It is necessary for the reader to recall in this connection that in northern Ohio the Cleveland shale, which is the highest member of the Ohio shale, is separated from a Carboniferous black shale above it, called the Sunbury, and from a Devonian black shale below, called the Huron, by drab shale and sandstone formations of variable thicknesses. It was easy in the early reconnoissance work of the Ohio Survey to confuse these three black shales. We have Newberry's own statement that he did confuse the Cleveland and Huron shales in northern Ohio. Concerning this he wrote: "This dip misled us and the thinning of the Erie shale, bringing the Cleveland down near to the Huron, caused these two to be confounded."‡ It appears that this confusion of the upper and lower shales was not detected by Newberry until 1886, or twelve years after he announced the discovery

* Proc. U. S. Nat. Museum, vol. xli, p. 213, 1911.

† The Sunbury Shale of Ohio, Jour. of Geology, vol. x, pp. 262–312, 1902.

‡ Mon. U. S. Geol. Survey, xvi, p. 127, 1889.

of the Waverly fauna at the base of the Cleveland shale which Bassler cites as evidence of the Carboniferous age of the Cleveland.

No one who has made a detailed study of the relations of the Carboniferous Sunbury to the two lower black shales from the northern to the southern boundary of Ohio, can doubt that the shale which Newberry called Cleveland in the 1874 Report* is the Sunbury shale. It was in this volume that Newberry published the list of Waverly fossils, including *Syringothyris typa*, which he reported to have been found below the Cleveland shale. It appears that the authenticity of this find was called in question during Professor Newberry's lifetime, and in a later discussion† of the matter he states that these fossils were collected by an assistant who was not able to relocate the horizon when requested to do so. The writer and Mr. P. V. Roundy searched very carefully the section from which this fauna was reported to have been obtained, but found immediately below the Cleveland shale a Chemung fauna without any trace of Waverly species. Many other geologists have studied the northern Ohio sections since Waverly fossils were reported by Newberry from below the Cleveland shale, but not one, so far as the writer is aware, claims to have found Waverly fossils at this horizon.‡ In view of these facts I think we may safely conclude that the collector of this fauna incorrectly identified the formation from which his Waverly fossils came.

If, for the reasons already stated, we dismiss from consideration the *Syringothyris* fauna as evidence in this case, we find that we must depend almost wholly for evidence of its age upon the affinities of the rich fish and conodont faunas which characterize the Cleveland shale. When Professor Newberry found himself unable to substantiate his previously published statement of the occurrence of a Waverly fauna at the base of the Cleveland shale, he continued to maintain the Carboniferous age of the formation chiefly on the evidence of the occurrence in it of three genera of Carboniferous fishes, namely, *Hoplonchus*, *Orodus*, and *Polyrhizodus*.§ Concerning this evidence it is well to recall that most of the fossil fishes described by Newberry were obtained for him by collectors on whom he depended for the correct designation of their geologic horizon. Since Professor Newberry had himself confused the Sunbury and Cleveland shales, the opportunities

* Geol. Survey of Ohio, vol. ii, Pt. 1, p. 95.

† Mon. U. S. Geol. Survey, xvi, p. 127, 1889.

‡ *Note:* It may be observed here that the Waverly fauna recently reported in Kentucky by Foerste (Ohio Naturalist, vol. ix, No. 7, pp. 515–523, 1 pl., 1909), was found below the Kentucky representative of the Sunbury shale.

§ The Paleozoic Fishes of North America, Mon, U. S. Geol. Survey, xvi, p. 128, 1889.

which existed for the collectors to confuse them are too evident to require discussion. If these genera occur in the Cleveland shale at Bedford, as Professor Newberry believed, recent workers in this field should have found at least one or two of them. We have, however, the testimony* of two paleoichthyologists, Dr. L. Hussakof and Prof. E. B. Branson, who have been persistent collectors in the Cleveland shale of northern Ohio, that they have never found any of these genera in it. Professor Branson† writes as follows:

"I have never collected any specimens of the genera mentioned in your letter, from the Cleveland shale, nor have I ever seen Carboniferous fish remains of any kind in the shales. . . . . We had quite a large collection of Cleveland shale material in Oberlin College Museum, but all of it indicated the Devonian age of the formation."

Dr. Hussakof indicates his experience in the following words:

"In regard to your query about *Hoplonchus, Orodus* and *Polyrhizodus*—I have never found any of them in the Cleveland shale."‡

In view of this kind of testimony from paleontologists thoroughly familiar with the fish fauna of the Cleveland shale, both through extended collecting and study of all the important collections made by others, we seem forced to conclude that the Carboniferous fishes which Newberry records from the Cleveland shale came probably from the Sunbury instead of the Cleveland.

When Newberry's monograph on the Paleozoic fishes of North America was published he was not aware that any of the twenty-eight fossil fishes which had been described from the Cleveland shale occurred in the Huron shale of northern Ohio, for he states§ that "none of the fossil fishes described from northern Ohio should be credited to the Huron." Progress has been made since this was written in our knowledge of the range of the Cleveland shale fishes. It has been comparatively small, however, because the group of collectors who have made the Cleveland shale famous for its fossil fishes, all lived on or near outcrops of this formation and gave comparatively little attention to the more remote area in northern Ohio in which the Huron shale reaches the surface. Branson‖ has, however, shown that at least one of the Cleveland shale fishes, *Dinichthys intermedius*, occurs in the Huron shale in its typical area near Huron, Ohio. It may be pointed out, too, that one at

* Letters to the writer.
† Letter to the writer, Nov. 23, 1911.
‡ Letter to the writer, Nov. 11, 1911.
§ Mon. U. S. Geol. Survey, xvi p. 127, 1889.
‖ Science, n. s., vol. xxviii, p. 94, 1908.

least of the fishes credited to the Huron shale by Newberry and unknown in the Cleveland, came, not from the Huron, but from the Olentangy shale at the base of the Huron. This conclusion is evident from the remarks concerning *Callognathus regularis* on page 60 of Newberry's monograph* although it is referred under the description of the species to the Huron shale. With increasing knowledge of the fish fauna of the Huron we may confidently expect the discovery of a considerable number of species common to both the Huron and the Cleveland shales. The general resemblance of the conodont faunas of the two formations seems fully to justify this presumption. The writer's collection from the Huron shale will, when studied, it is believed, add other species of fishes to those which are known to be common to the Huron and Cleveland shales.

Professor Newberry, in his latest reference to the conodonts of the Cleveland shale, dismissed the evidence which these fossils might have yielded him with the statement that "the millions of conodonts in it have no geological significance."† This view is evidently not shared by Dr. Bassler, who has based his correlation of the Chattanooga shale of Tennessee and the Cleveland shale of Ohio entirely on the similarity of the conodont faunas in the two. Nor is it shared by the writer, although, as previously stated, detailed discussion of the evidence which this group will afford must wait the description of the conodont faunas recently discovered by the writer in the Huron shale in northern Ohio. A preliminary examination of the conodont fauna of the Huron shale shows that it is very similar to that of the Cleveland shale. The most important facts now available, as bearing directly on the question of the age of the Cleveland shale, relate to the known range outside of Ohio of the species which have been recognized in it. Only three of the Cleveland shale species of conodonts have thus far been recorded from other formations. These are *Prionides angulatus* Hinde, *Prionides erraticus* Hinde, and *Polignathus dubius* Hinde. These species are recorded only from Hamilton and Genesee horizons‡ elsewhere, so that

* Mon. U. S. Geol. Survey, No. 16, 1889.

† Mon. U. S. Geol. Survey, xvi, page 128, 1889.

‡ Hinde, George H., On Conodonts from the Chazy and Cincinnati Group of the Cambro-Silurian, and from the Hamilton and Genesee-shale Divisions of the Devonian, in Canada and the United States. Quart. Jour. Geol. Soc., London, vol. xxxv, pp. 351–368, 1879.

Clarke, J. M., Annelid Teeth from the lower portion of the Hamilton Group and from the Naples Shales of Ontario Co., N. Y. N. Y. State Geol., Sixth Ann. Rep. for 1886, pp. 30–33, pl. A1.

Grabau, A. W., The Palæontology of Eighteen Mile Creek and the Lake Shore Sections of Erie County, New York. Bull. Buffalo Soc. Nat. Sci., vol. vi, pp. 150-158, figs. 33A–33I, 34–46, 1899.

the conodonts, so far as their evidence is recorded, indicate a Devonian age for the Cleveland shale.

Résumé of conclusions concerning age of unconformity.—Briefly summarizing the discussion of the question of the age of the Cleveland shale, we may say that (1) the evidence of the Waverly fauna originally brought forward by Newberry and restated by Bassler should be eliminated from consideration, because neither Newberry nor any of his successors have been able to substantiate it by finding a similar fauna at the base of the Cleveland. (2) Later workers have failed to find any of the Carboniferous fishes claimed by Newberry to occur in it. (3) Some of the large fossil fishes which characterize the Cleveland are represented by identical species in rocks of demonstrated Devonian age. (4) The Cleveland shale conodonts, so far as their range has been recorded, are known elsewhere only from Devonian rocks.

If there is extant no valid evidence of the Carboniferous age of the Cleveland shale, as the preceding review of it appears to indicate, the correlation of the Chattanooga shale, either in part or *in toto* with the Cleveland, affords strong evidence for, instead of against, its Devonian age as has been assumed by Dr. Bassler. This evidence in the north is fully corroborated in the south by the discovery of a conodont fauna in a black shale of admitted Devonian age in east Tennessee which is identical with that in the Chattanooga shale. Thus we see that correlation of the Cleveland shale with its equivalent or partial equivalent, both in northern Ohio and eastern Tennessee, indicates its Devonian age.

With respect to the unconformity at the base of the Chattanooga shale, the important and obvious fact which appears from this discussion of the age of the Chattanooga is, that it does not transgress Devonian time. The field work of the writer has furnished convincing evidence, both stratigraphic and faunal, that the Chattanooga shale in Kentucky represents the Huron as well as the higher beds of the Ohio shale. Detailed presentation of the faunal and stratigraphic evidence of the continuity of the Huron shale across Kentucky must, however, await the appearance of the writer's report on the fauna and stratigraphy of the Chattanooga shale. Only the evidence of one of the fossil fishes will be introduced here. Dr. L. Hussakof writes* concerning one of the fossil fishes obtained from this horizon by the writer and Mr. P. A. Bungart on Copperas Creek, east of Indian Fields, Clarke Co., Kentucky, as follows:

"The specimen from Copperas Creek is without any question *Dinichthys herzeri* Newberry, the species supposed to be indica-

* A letter to the writer, Nov. 28, 1911.

tive of the Huron shale. Your specimen shows even the series of denticles along the front face of the 'premaxillary' just as in the type specimen."

The fauna which most geologists have held to indicate a Genesee age for the Chattanooga in Kentucky the writer has found on all sides of the Cincinnati arch in Kentucky, but confined to the lower beds of the formation. There appear to be no good grounds for questioning this assignment of the basal beds of the Chattanooga to Genesee time. The land conditions represented by the unconformity could not then have continued later than the Genesee. Their initiation could not have been earlier than late Hamilton. Limestone of this age underlies the shale near Louisville. Hamilton fossils have been found in the Harpeth River valley a short distance south of the Kentucky-Tennessee boundary. When the Devonian limestone has been carefully studied in the intermediate territory in Kentucky, Hamilton fossils will doubtless be found in various localities where the rocks of this age have partially escaped erosion. It would appear, therefore, that the unconformity involved a time representing either early Genesee or late Hamilton time, or both.

The evidence available with regard to the age of the black shale sediments in eastern Tennessee and southwest Virginia, indicate land conditions that were contemporaneous with those which have been described in Kentucky. The unconformity at the base of the Chattanooga shale in eastern Tennessee* indicates that a land area existed in that region previous to Chattanooga sedimentation which was doubtless continuous with land conditions in southwest Virginia and central Tennessee and Kentucky, but which may have begun at an earlier period than in Kentucky. The unconformity in eastern Tennessee and southwestern Virginia is followed by shales with a fauna similar to that which we find above it in the Chattanooga in Kentucky. We must conclude, therefore, that while pre-Chattanooga land conditions may have begun considerably earlier, they did not last appreciably longer in eastern Tennessee and southwest Virginia than in Kentucky.

* Keith, Arthur, Knoxville, Loudon, Maynardsville, and Morristown Folios, U. S. Geol. Survey.

ART. XVIII.—*A Suggestion for Mineral Nomenclature;* by HENRY S. WASHINGTON.

Introduction.—That the science of mineralogy may be regarded as a branch of descriptive chemistry (but one which deals only with substances occurring in nature) is recognized in the prevalent mineral classifications, where the chemical composition is the primary and most important factor. The character of the negative (acidic) ion controls for the formation of the largest classes, and subclasses may be based on the character of the positive (basic) ion, in some cases preceded by separation into anhydrous and hydrated compounds. In all these subclasses minerals which belong to the same acidic type are placed together. The ultimate smallest groups, which bring together minerals regarded as most closely related, are based on similarity in crystal form, dependent on isomorphous replacement, either entire or partial, and either in the negative or the positive portion of the molecule; while again dissimilarity in crystal form due to polymorphism of substances with the same empirical chemical composition, serves to distinguish between groups chemically alike.

The crystal form, therefore, is a necessary diagnostic, as important for the formulation of our idea of any mineral as its chemical composition. As Miers* expresses it, for the definition of minerals "we are forced to employ at least two properties, namely the chemical composition and the crystalline form: these two, when completely known, are necessary and sufficient for the definition and determination of any mineral." The less important characters, such as color, structure, habit, state of aggregation, and minor details of chemical composition, are (or should be) used only to distinguish very subordinate (varietal) divisions, and, as Miers justly says, far too much importance has been generally assigned to them in naming minerals. Many cases will also occur to every mineralogist of minerals which stand alone and can only be referred to indefinite positions in the classes, dependent on the general character of the negative ion; that is, they show no intimate relations with other minerals through both their chemical and crystallographic characters and constitute the sole representatives of potential groups, which thus correspond to the monotypic genera of botany and zoology.

In this necessary utilization of both chemical composition and crystallographic characters, the definition and classification of minerals differ from, and may justly be considered as in

* H. A. Miers, Mineralogy, London, 1902, p. 2.

advance of, the classification and definitions of descriptive chemistry, which only take cognizance of the ultimate chemical composition of the substance as revealed by analysis, and its molecular structure as shown by its reactions, replacements, molecular weight, etc. To the chemist, $CaCO_3$ is only calcium carbonate, whether its crystal form is trigonal or orthorhombic, with correlated differences in specific gravity, optic characters, etc. To the mineralogist these two forms are different minerals, though the chemical composition is expressed by the same empirical formula.

This recognition of polymorphous or physically isomeric forms of the same empirical molecule as different substances and the converse relationship between substances of closely similar crystal form and of the same chemical type, though differing in composition through isomorphous replacement, is but a logical following out of the teachings of physical chemistry. It is an extension of the definition of "substance" to include, in addition to the chemical composition, the relations of the physical and chemical characters of matter to the conditions of equilibrium which control crystallization. That the recognition of the essential difference between substances (in this sense) with the same ultimate chemical composition is valid and necessary, is shown by consideration of such cases as diamond and graphite (C), pyrite and marcasite (FeS_2), or calcite and aragonite ($CaCO_3$). In these the differences in the physical characters, and to no less an extent in many of the chemical characters, as resistance to reagents, of the members of each pair are so great that they must be regarded as distinct substances. This would be true even from the purely chemical point of view, since the physical differences, especially those like specific gravity and specific heat, indicate differences in the molecular weight and very probably in molecular structure.

It may be noted here that among minerals there are few ascertained cases of chemical isomerism, in which the distinct physical and chemical characters, due to profound and persistent differences in the molecular structure, persist after the substance has been changed into an amorphous state, as by fusion or solution, and then recrystallized.* Numerous illustrations of this are furnished by organic chemistry, the most classical being that of urea and ammonium isocyanate. Among minerals it is difficult to prove the existence of such cases, though they unquestionably occur, and Groth† regards pyrite and marcasite, and cyanite, sillimanite and andalusite, respec-

* Groth, Introduction to Chemical Crystallography, New York, 1906, p. 3.

† Groth, Chemische Krystallographie, Leipzig, Pt. I, 1906, p. 155, and Pt. II, 1908, p. 258.

tively, as cases in point. Whether there is any essential difference between physical and chemical isomerism may perhaps be doubted, but further discussion of this topic is uncalled for here.

In spite of this advanced state of the classification of mineralogy, the nomenclature is in much the same condition as in the time of Pliny, when minerals were named after their qualities, localities, or uses, with the systematic termination *-ites* or *-itis* (modern *-ite*), the only innovations being the introduction of names after persons and certain other arbitrary terminations. Despite attempts to introduce binomial names, analogous to those of botany and zoology, or those based on chemical characters, systematic mineralogy has adhered closely to the nomenclature of the first century A. D.*

As a consequence, mineral nomenclature, like that of the older rock classifications, is unable to express the facts of classification. Roots derived from names of places or persons can convey in themselves absolutely no idea of the mineralogical characters, and even those derived from chemical or physical characters are applicable to many different minerals. Thus cuprite applies equally well to CuO as Cu_2O, and octahedrite would be an appropriate name for magnetite, franklinite, or fluorite. All such name roots are purely arbitrary in their mnemonic connotations, but at the same time, by long association, a large proportion of mineral name roots convey very definite ideas of the mineral and chemical characters.

Again, with the uniform and monotonous general use of a single termination (-ite), and the arbitrary and unsystematic employment of others, the characters and relations of minerals, and even of mineral groups, are concealed. No distinction is evident from the name between a rare or uncharacteristic varietal form of a certain mineral (as hiddenite or sagenite), and a large mineral group which may include many distinct minerals (as zeolite or chlorite). In the case of a few of the commonest and largest groups of related minerals we have names, fortunately distinctive because of their terminations, which may be applied to the group as a whole, as spinel, feldspar, garnet, pyroxene, amphibole, mica; and the general usefulness and common application of these is sufficient evidence of the value of such group names. In other cases the difficulty of expressing relationships is got round and the need supplied by the word "group" after the name of a typical representative: as the pyrite, calcite, aragonite, olivine, and apatite groups. In all these group names the underlying idea which connects the members is adherence to a certain type of chemical formula, with isomorphous replacement, and, of equal importance, close

* Cf. Dana, System Mineralogy, 1892, p. xl.

similarity in the crystal form as shown by the system, axial relations, and often cleavage. As regards the crystal system, in the largest groups this similarity need not amount to identity, as in the feldspars, pyroxenes and amphiboles, but in general the idea of a mineral group implies identity of crystal system modified only in its details by the slight morphotropic changes consequent on isomorphous replacement.

It will thus be seen that a mineral nomenclature should be able to express in the name a fairly definite idea of the chemical composition and type of compound, as well as the crystal system, and at the same time indicate the relations to other minerals, and especially the membership of a mineral in its particular "group." It is the object of this paper to lay stress on the importance of the recognition in mineralogical classification of this idea of mineral groups, distinguished by close similarity in chemical composition and crystal form, and made up of distinct mineral members, and to suggest a nomenclature which will express these relations, based on the general principles of chemical nomenclature, but providing also for the recognition of the crystal form as an element of the classification.

The System of Nomenclature.—As compared with the carbon compounds, minerals, and especially the silicates, present very great difficulties in the study of their molecular constitution. This is because of their high fusing points, non-volatility, insolubility, general chemical stability at ordinary or even very high temperatures (so that replacements of portions of the molecule are difficult), and impossibility of determination of the molecular weight, assuming that the term "molecular weight" is applicable to a solid body. Although we now realize the importance of this branch of mineralogy, and are beginning to recognize, especially among the silicates, the complex chemical constitution of many minerals and the existence of certain radicals or atomic groups analogous to those of organic chemistry, yet we are generally forced to be content with the expression of the chemical composition by simple empirical formulas. The constitutional and graphic formulas of but very few minerals can be given with any degree of confidence, and in the vast majority of cases we are absolutely in the dark.

Mineralogy is essentially in the condition of organic chemistry of the early days, when the composition of alcohol could only be expressed empirically as C_2H_6O, that of lactic acid as $C_3H_6O_3$, and that of urea as CH_4ON_2; whereas at present we can confidently express them by the constitutional formulas, $(C_2H_5)(OH)$, $(CH_3)(CHOH)(COOH)$, and $(CO)(NH_2)_2$, systematically known as ethyl alcohol, *a*-hydroxypropionic acid, and carbonyl amide, the last differing in constitutional formula from the isomeric ammonium isocyanate, $(CON)(NH_4)$.

Indeed, the theory of mineral constitution at present is in many ways analogous to the "theory of types" in organic chemistry, formulated by Gerhardt about 1850, as is seen in the general reference of the silicate minerals to simple silicic acids, H_2SiO_3, H_4SiO_4, $H_6Si_2O_7$, etc. Kekulé's "theory of linked atoms" has now superseded this in organic chemistry,* and the applicability of this to mineral chemistry has only recently begun to be realized.

The study of the molecular constitution of minerals and attempts at the establishment of constitutional formulas have been undertaken by Tschermak, Groth, Clarke, and many others, either through direct experiment or study of alteration products, but so far with doubtful success in most cases, and it will probably be many years before mineralogy attains to the knowledge requisite for formulas like those of modern organic chemistry.

In three important papers Penfield† established the complex character of the acidic portion of the tourmalines and amphiboles, and showed the effect of the mass action of the complex acid in controlling crystallization, allowing replacement of the hydrogen atoms of the hypothetical acid by very different elements or radicals, and with different valences, but without change in crystal form. He also speaks of these acids as tourmaline acid and amphibole acid, with the implication that an essential character of their salts is adherence to the particular crystal form of tourmaline and amphibole respectively.

More recently the problem of the constitution of some silicates has been studied by Tschermak, Baschieri and others.‡ These investigators have identified certain silicic acids, which they call after the mineral names, among them being: anorthitic acid (H_2SiO_3) albitic acid ($H_2Si_3O_7$), leucitic acid ($H_4Si_2O_6$), heulanditic acid ($H_{10}Si_6O_{17}$), granatic acid ($H_4Si_3O_8$ and datolitic acid ($H_2Si_2O_5$). Their method, it may be remarked, does not apparently permit of discrimination between a purely silicic or an alumo- or boro-silicic acid, and none of these workers suggests, like Penfield, that the acid or the acid name implies the crystal form of its salts.

It is suggested here that this concept of Penfield of silicate minerals as salts of mineral acids, in many cases of much greater complexity than is implied by the empirical formula, with the implication of the adherence of the salts to a charac-

* Cf. C. Schorlemmer, Rise and Development of Organic Chemistry, London, 1894, pp. 39, 69, and 155.

† This Journal, vii, p. 97, 1899: x, p. 19, 1900; xxiii, p. 23, 1907.

‡ Tschermak, Sb. Ak. Wiss. Wien, cxii (1), p. 355, 1905, cxiv (1), p. 455, 1905, cxv (1), p. 217, 1906. E. Baschieri, Proc. verb. Soc. Tosc., xvi, p. 84, 1907; Atti Soc. Tosc. Mem., xxiv, p. 133, 1908. Himmelbauer, Sb. Ak. Wiss. Wien, cxv (1), p. 1184, 1906.

teristic crystal form, be extended to minerals in general and made the basis of a mineral nomenclature. From this point of view silicate minerals would not be considered simply as salts of orthosilicic acid (H_4SiO_4), metasilicic acid (H_2SiO_3), disilicic acid ($H_2Si_2O_5$), and so forth; as substitution derivatives of normal aluminum silicates according to Clarke, (which correspond to the old theory of types); or of multiples of silica according to Goldschmidt: but each group would be considered as salts of a particular silico- or alumino-silico- acid characterized by the particular crystal form and symmetry of its salts, and capable of ismorphous replacement either of its basic hydrogens or in the acidic portion.

This concept may be most appropriately applied to mineral groups, distinguished as at present by identity of chemical type and close similarity in crystal form, but it may be equally well applied to monotypic "groups", represented, so far as now known, by only one mineral and which exhibit no evident near relationships, either chemical or crystallographic, as is the case with beryl and calamine. It is also clear that it would be applicable to minerals of simple as well as highly complex constitution. A further point, and one of great importance, is that a system of nomenclature based on this concept would be applicable whether the structural or constitutional formula, or even the exact chemical composition, of the mineral acid were known or not, as the salts of a given mineral acid (in this sense) would be identifiable and their relationship established by their conforming to a certain empirical chemical formula and crystal form. Thus the various pyroxenes and amphiboles are members of two different, but well-characterized, and universally recognized "natural" groups, though we are as yet almost wholly ignorant of their molecular constitution, knowing only that they may be referred, but do not necessarily belong, to the metasilicates, but are undoubtedly much more complex than is indicated by the empirical formulas. We cannot even determine which group is the more complex.

Such a nomenclature would be rational and would be analogous to that of inorganic chemistry, of which mineralogy may be considered to be a branch, except that the crystallographic character is implied in the name and is an integral part of the definition. It might even be suggested that such a nomenclature as is here suggested is also applicable to artificial salts, and would be found especially useful with such highly complex compounds as the silicotungstates, phosphomolybdates, cobalt-ammine compounds, the various groups of which might be named after chemists who have been especially identified with their study.

While in advance of the present inadequate nomenclature,

in that not only chemical and crystallographic characters but mineral relationships would be indicated, the suggested nomenclature would not, nor is it intended to, replace this for general use. The two would exist simultaneously, though used for different purposes, as the new nomenclature would lend itself readily to, and would probably aid in, the study and investigation of the molecular constitution of minerals and in other ways. In ordinary parlance and for usual purposes minerals, especially the common ones, would go by their present names, while when greater precision and exactitude were needed, especially in theoretical discussion, the suggested nomenclature could be used. Similarly, in inorganic and especially in organic chemistry, the common names are ordinarily used instead of the longer and more complex scientific names, which are systematic and indicate the chemical constitution.

For the purposes of such a nomenclature the large store of present mineral names may be drawn on for the necessary roots, since these roots would have in most cases sufficient mnemonic connotations to give directly an idea of the general chemical and crystal characters. Well-known or fairly well-known roots are sufficiently numerous to cover nearly the whole field of mineralogy. Though new minerals are being discovered with some frequency, representatives of entirely new mineral groups are comparatively rare, as many of the new minerals are referable to groups already known, and with increasingly exact knowledge of chemical composition and molecular structure, many minerals of hitherto unknown or uncertain affinities are being correlated with other groups, as the sodalites and the garnets.

It is suggested that the names of minerals (excepting for the present the elements and hydrocarbons) be formed similarly to those of oxides and salts in inorganic chemistry, as ferric oxide, sodium chloride, potassium sulphate, but with the crystal character implied in the name. Such mineral names will be binomial in general, composed of one term denoting the basic (positive) portion of the molecule and another denoting the acidic (negative) portion. As the acidic portion is of major importance in classification it will be considered first.

The name of the mineral acid, or the acidic portion of its salts, will imply not only general chemical composition and type, but the crystal symmetry and general crystallographic relations of its salts, subject to the morphotropic changes due to isomorphous replacement.

The acid (*negative*) *radical* of a mineral group will be denoted by a root derived from the present name of a typical and appropriate member, preferably that best known or first named. To this root, in general shorn of its present termination (except

for euphony or to avoid confusion with ordinary chemical salts), will be affixed the termination used in inorganic chemistry for the type of compound represented. For the mineral acid itself this termination would then be *-ic*, for a binary compound (oxide, sulphide, etc.) it will be *-ide*, for the sulpho-acid and analogous salts,* and for the oxy-acid salts, it will be *-ate*. As noted above, it will not be necessary to know the constitutional formula of the acid or mineral group to name it, as it may be defined by its empirical formula and crystal form.

The water of crystallization of hydrated mineral salts may in general be considered for the purposes of nomenclature as part of the negative portion of the molecule, since not only do nearly all hydrates differ crystallographically from the anhydrous salts, but the crystal form varies with the number of molecules of water present when several hydrates exist.

Such simple designations, implying always the crystal system characteristic of the salts of the mineral acid, will suffice for the negative (acidic) portion of isomorphous mineral groups in which the acid radical is identical in all (the base alone varying through isomorphous replacement), or for monotypic mineral groups. Thus, the members of the calcite, aragonite, and olivine groups are respectively salts of calcitic, aragonic, and olivinic acids, or calcitates, aragonates, and olivinates; while cyanite and calamine are the only known disthenate and calamate respectively.

When, however, in a group the chief element in the acidic portion is replaceable isomorphously, by different elements, as with the pyrite and apatite groups or, as in the pyroxenes and feldspars, there are marked differences in the crystal symmetry, the acidic portion remaining chemically the same, it becomes necessary to indicate these differences in the nomenclature. This may best be done in two ways, according to which of the cases is involved.

In the case of isomorphous replacement in the acidic portion the different compositions may be expressed by the use of appropriate prefixes to the acidic term used without a hyphen. Thus all members of the pyritohedrally isometric pyrite group would be pyrides, but pyrite and hauerite would be sulpyrides, and smaltite and chloanthite arsenpyrides. Among the silicates the presence of unusual or non-typical elements partially replacing silica may be expressed by similar syllables prefixed to the acidic name with a hyphen. Thus rosenbuschite and lavenite would be zirco-diopsidates. In some cases, when the isomorphous replacement in the acidic portion is complex, it may be advisable to use very much shortened syl-

* The regular termination *-ite* would be inadvisable for these, as liable to confusion with present names.

labic forms for the various elements, as will be explained when the naming of the base is considered.

In the case of the more complex mineral acids, especially among the silicates, as the alumo-silicates or boro-silicates, in which only the subsidiary acidic element is isomorphously replaceable, the replacement will be indicated by the use of appropriate chemical syllables prefixed to the acidic term, used with a hyphen. Thus, if the garnets are regarded as salts of complex alumo-. etc.- acids, they would be called alumi-garnetates, ferri-garnetates, and chromi-garnetates, and similarly members of the datolite group would be bori-datolates, alumi-datolates or yttri-datolates, represented by datolite, euclase, and gadolinite. This will serve to distinguish such complex salts from those of mineral acids in which one characteristic element exists and is wholly replaced, as in the apatite group, which would be called phosphapatates, arsenapatates, and vanadapatates.

When the differences are those of crystal symmetry, as in the pyroxene and feldspar groups, the general group names will be formed as above by a root derived from the present group name or best representative, followed by the terminations *-oic* for the acid, *-ode* for binary compounds, and *-ote* for sulpho- and oxy-salts. The various subgroups, distinguished by differing but related crystal systems, will be designated by the use of the appropriate roots and regular terminations as described above. Thus all the members of the pyroxene group would be salts of pyroxenoic acid or pyroxenotes, while the orthorhombic members would be hypersthenates, the monoclinic diopsidates, and the triclinic rhodonates.

The rare cases among minerals of homologous series, corresponding to the paraffins and olefines of organic chemistry, in which each member differs from the preceding by a constant increase of a certain atomic group, must also be considered. These are best represented by the humite group, better called "series." The members of such a series may be designated as to the acidic portion by the use of the prefixes *uni-*, *bi-*, *ter-*, etc., to indicate the number of the varying radical, as will be shown later.

The base or bases present will be indicated by the use of the name or names of the positive element or elements, either as such or expressed by appropriate syllables when more than one base is present. It may be suggested that the relative importance of the several isomorphous bases present be indicated by a definite order in the syllables and that the most important be placed last, the preceding ones being in the nature of modifiers. This can also be emphasized by using the full name for the most important base, and a contracted adjectival form,

ending in *i* or *o*, for the others. When two bases are of equal importance, present in about equal molecular amounts, the combined full names may be used, though this last might better be reserved for definite double salts, as dolomite. Illustrating the above idea, forsterite would be called magnesium olivinate, most chrysolite ferro-magnesium olivinate, hyalosiderite might be magnesi-ferrous olivinate, and fayalite ferrous olivinate.

In many minerals, however, several bases are present and in these cases, and even when there are only two, the designation of the base may become long and cumbrous. It may therefore be desirable to have all the bases represented by syllables as compact and condensed as possible, so long as this can be done without sacrificing clearness. For this purpose it is suggested that the first syllable of the element name may be used, joined together without linking vowels or hyphens, the order being significant of the relative importance, as above. Thus enstatite would be magnesium hypersthenate, bronzite fermag hypersthenate, and a highly ferrous hypersthene magfer hypersthenate.

With the increasing recognition of the presence of radicals in minerals it becomes necessary, as a matter of convenience, to designate these by short terms, and here we may well follow the lead of organic chemistry, where we find such indispensable radical names as ethyl, butyl, phenyl, acetyl, derived from their most prominent compounds. Similarly we might designate the mineral radical, $Al(F,OH)$, essential in topaz, as topyl; $Mg(F,OH)$, present in the chondrodrite series, as chondryl; and (BOH), which Penfield has shown to be present in tourmalines, as tourmyl. Such radical names would take the place of element names when present as bases.

The objection will, of course, be raised against the use of such syllables that they are barbarous, uncouth, and cacophonous. In reply to this it may be said that, while they will undoubtedly appear so at first, usage will gradually render them easy, natural, and less awkward. As a case in point may be cited the terminology of organic chemistry, where we find such words as carboxyl, aldoxim, azoxybenzol, glyoxal, phthalisoimide, and a host of others. The same objections could have been, and probably were, raised against these, but to express the lengthy and complicated names of organic compounds the chemist has found such syllables absolutely necessary. They are readily understandable and give an immediate insight into the composition of the substance, have wholly lost their original "barbarousness," and new ones are freely coined when needed.

Acid and basic salts present some difficulties, as it is not always possible as yet to determine the function of hydrogen or hydroxyl in minerals. When definitely known to be basic

or acid salts they may be so designated, but in general they may be designated by special acidic names for the group, since the acidity or basicity almost always determines a crystal form different from that of the normal salt.

Names formed as suggested above have certain analogies with some of the present mineral names, in which isomorphous replacement is indicated by the use of chemical modifiers, as soda-microline, manganopectolite, cuprodescloizite, natrojarosite, plumbo-jarosite and soda-mica. Even in these we can see the lack of system in present nomenclature, since these names belong to two distinct categories. In the one the modifier expresses only partial replacement of the characteristic element of the type mineral by an isomorphous one, as in the first three examples, which are presumably cases of solid solution and should be regarded as varieties of the type, or as intermediate between two extremes. In the last three cases there is *entire* replacement by the element denoted in the name, and such minerals are definite compounds and must be regarded as distinct species. For this reason natrojarosite and plumbojarosite are better entitled to recognition as distinct minerals than are soda-microcline (anorthoclase) or manganopectolite, and should have special names not formed on this plan, while paragonite has properly replaced the earlier soda-mica, which last should be used for a mica in which the potassium is only partially replaced by sodium.

The names of the suggested nomenclature are properly applicable only to minerals of the second kind just mentioned, that is to definite compounds, since it is essentially an inorganic chemical nomenclature, in which mixed crystals should be named by calling them mixtures of their components. In mineralogy the case is somewhat different, it is true, as such mixed crystals are often important and fairly well-defined mineral species, and names for them are necessary. Some latitude and discretionary power must, therefore, be allowed, and while all rather indefinite mixed crystals need not receive specific recognition or names, there will be many cases, especially when the mixture is of mineralogical importance, fairly constant in composition, or with some approximation to simple stoichiometric ratios, when names as above should be bestowed. To meet the common case of the indefinite or variable isomorphous replacement, it may be suggested that the syllable *-ic* be added to the compounded elemental syllables used for the base. Thus the various hypersthenes and bronzites would be called collectively fermagic hypersthenates, and the lime-soda feldspars would be calsodic albates.

Illustrations of the System.—It is impracticable to give here a complete illustration of the application of the system to

all known minerals, so that only a few selected cases are given which will illustrate the points brought out above. It is purposed to publish elsewhere a fairly complete list, already prepared, which will serve as a basis for the suggested nomenclature.

Sphalerite Group.

Sphalerides, R″(S,Se,Te), isometric, tetrahedral.

Sphalerite, ZnS	Zinc sulsphaleride
Metacinnabarite, HgS	Mercury sulsphaleride
Alabandite, MnS	Manganese sulsphaleride
Tiemannite, HgSe	Mercury selsphaleride
Onofrite Hg(S,Se)	Mercury selsulsphaleride
Coloradoite, HgTe	Mercury telsphaleride

Pyrite Group.

Pyrides, $R(S,As,Sb)_2$, isometric, pyritohedral.

Pyrite, FeS_2	Iron sulpyride
Hauerite, MnS_2	Manganese sulpyride
Laurite, RuS_2	Ruthenium sulpyride
Smaltite, $CoAs_2$	Cobalt arsenpyride
Chloanthite, $NiAs_2$	Nickel arsenpyride
Sperrylite, $PtAs_2$	Platinum arsenpyride
Cobaltite, $Co(S,As)_2$	Cobalt sularsenpyride
Gersdorffite, $Ni(S,As)_2$	Nickel sularsenpyride

Marcasite Group.

Marcasides, $R(S,As)_2$, orthorhombic.

Marcasite, FeS_2	Iron sulmarcaside
Löllingite, $FeAs_2$	Iron arsenmarcaside
Safflorite, $CaAs_2$	Cobalt arsenmarcaside
Rammelsbergite, $NiAs_2$	Nickel arsenmarcaside

Hematite Group.

Hematides, R_2O_3, trigonal.

Corundum, Al_2O_3	Aluminum hematide
Hematite, Fe_2O_3	Iron hematide
Ilmenite, $(Fe,Ti)_2O_3$	Titanferri hematide
Geikielite, $(Mg,Ti)_2O_3$	Titanmagnesi hematide
Pyrophanite, $(Mn,Ti)_2O_3$	Titanmangani hematide

If the members of this group are considered to be aluminates, ferrates, etc., the appropriate names would be: Aluminum alhematate, iron ferhematate, iron titanhematate, magnesium titanhematate, and manganese titanhematate.

Calcite Group.

Calcitates, R''_2CO_3, trigonal.

Calcite, $CaCO_3$	Calcium calcitate
Magnesite, $MgCO_3$	Magnesium calcitate
Dolomite, $CaMg(CO_3)_2$	Magnesicalcium calcitate
Ankerite, $(Mg,Fe)Ca(CO_3)_2$	Fermag-calcium calcitate
Siderite, $FeCO_3$	Ferrous calcitate
Rhodochrosite, $MnCO_3$	Manganese calcitate

Feldspar Group.*

Feldspathotes, $\left\{ \begin{matrix} R'AlSi_3O_8 \\ R''Al_2Si_2O_8 \end{matrix} \right\}$, monoclinic-triclinic.

Adular Subgroup.

Adularates, monoclinic.

Orthoclase, $KAlSi_3O_8$	Potassium adularate
Barbierite, $NaAlSi_3O_8$	Sodium adularate
Celsian, $BaAl_2Si_2O_8$	Barium adularate

Albite Subgroup.

Albates, $R'AlSi_3O_8$, triclinic

Microcline, $KAlSi_3O_8$	Potassium albate
Albite, $NaAlSi_3O_8$	Sodium albate
Anorthoclase, $(K,Na)AlSi_3O_8$	Potassisodium albate

Anorthite Subgroup.

Anorthates, $R''Al_2Si_2O_8$, triclinic.

Anorthite, $CaAl_2Si_2O_8$	Calcium anorthate
Carnegieite, $Na_2Al_2Si_2O_8$	Sodium anorthate

Mixed Salts.

Oligoclase, Ab_2An_1	Caldisod anorth-albate
Andesine, Ab_1An_1	Sodcal alb-anorthate
Labradorite, Ab_1An_2	Soddical alb-anorthate

Pyroxene Group.

Pyroxenotes, $\left\{ \begin{matrix} R''_2Si_2O_6 \\ R''R'''_2SiO_6 \end{matrix} \right\}$, orthorhombic, monoclinic, triclinic.

* The constitution and relations of the feldspars, lenads and zeolites will form the subject of a subsequent paper.

HYPERSTHENE SUBGROUP.

Hypersthenates, orthorhombic.

Enstatite, $Mg_2Si_2O_6$	Magnesium hypersthenate
Bronzite, $(Fe,Mg)_2Si_2O_6$	Ferromagnesium hypersthenate
Hypersthene, $(Mg,Fe)_2Si_6O_2$	Magnesiferrous hypersthenate

DIOPSIDE SUBGROUP.

Diopsidates, monoclinic.

Diopside, $CaMgSi_2O_6$	Calcimagnesium diopsidate
Hedenbergite, $CaFeSi_2O_6$	Calciferrous diopsidate
Wollastonite, $Ca_2Si_2O_6$	Calcium diopsidate
Augite, $\left\{\begin{array}{l} m\mathrm{CaMgSi_2O_6} \\ n\mathrm{(Mg,Fe)\,(Al,Fe)_2SiO_6} \end{array}\right.$	Alfercalmag diopsidate
Acmite, $NaFeSi_2O_6$	Ferrisodium diopsidate
Jadeite, $NaAlSi_2O_6$	Alumisodium diopsidate
Spodumene, $LiAlSi_2O_6$	Alumilithium diopsidate
Pectolite, $HNaCa_2Si_3O_9$	Acid sodicalcium diopsidate

RHODONITE SUBGROUP.

Rhodonates, triclinic.

Rhodonite, $Mn_2Si_2O_6$	Manganese rhodonate
Babingtonite, $\left\{\begin{array}{l} m\mathrm{(Ca,Fe)_2Si_2O_6} \\ n\mathrm{Fe_2Si_3O_9} \end{array}\right.$	Ferricalcium rhodonate

OLIVINE GROUP.

Olivinates, $R''_2Si_2O_4$, orthorhombic.

Forsterite, $Mg_2Si_2O_4$	Magnesium olivinate
Monticellite, $CaMgSi_2O_4$	Calcimagnesium olivinate
Chrysolite, $(Fe,Mg)_2Si_2O_4$	Ferromagnesium olivinate
Fayalite, $Fe_2Si_2O_4$	Ferrous olivinate
Tephroite, $Mn_2Si_2O_4$	Manganous olivinate
Glaucochroite, $CaMnSi_2O_4$	Calcimanganous olivinate

CHONDRODITE SERIES.

Chondrodates, $R''_{2n-1}(R''(F,OH))_2(SiO_4)_n$, orthorhombic

Prolectite, $Mg(Mg(F,OH))_2(SiO_4)$	Magnesium uni-chondrodate
Chondrodite, $Mg_3(Mg(F,OH))_2(SiO_4)_2$	Magnesium bi-chondrodate
Humite, $Mg_5(Mg(F,OH))_2(SiO_4)_3$	Magnesium ter-chondrodate
Leucophœnicite, $Mn_5(MnOH)_2(SiO_4)_3$	Manganese ter-chondrodate
Clinohumite, $Mg_7(Mg(F,OH))_2(SiO_4)_4$	Magnesium quadri-chondrodate

Datolite Group.

Datolates, $R'_2R'''_2Si_2O_{10}$, monoclinic.

Datolite, $H_2Ca_2B_2Si_2O_{10}$	Acid calcium bori-datolate
Euclase, $H_2Gl_2Al_2Si_2O_{10}$	Acid glucinum alumi-datolate
Gadolinite, $FeGl_2Y_2Si_2O_{10}$	Ferro glucinum yttri-datolate
Homilite, $FeCa_2B_2Si_2O_{10}$	Ferro calcium bori-datolate

Spinel Group.

Spinelates, $R'R'''_2O_4$, isometric.

Spinel, $MgAl_2O_4$	Magnesium alumispinelate
Hercynite, $FeAl_2O_4$	Ferrous alumispinelate
Gahnite, $ZnAl_2O_4$	Zinc alumispinelate
Magnetite, $FeFe_2O_4$	Ferrous ferrispinelate
Chromite, $FeCr_2O_4$	Ferrous chromispinelate

Apatite Group.

Apatates, $R'_5(F, Cl)((P, As, V)O_4)_3$, hexagonal.

Apatite, $Ca_5(F,Cl)(PO_4)_3$	Calcium phosphapatate
Pyromorphite, $Pb_5Cl(PO_4)_3$	Lead phosphapatate
Mimetite, $Pb_5Cl(AsO_4)_3$	Lead arsenapatate
Svabite, $Ca_5F(AsO_4)_3$	Calcium arsenapatate
Vanadinite, $Pb_5Cl(VO_4)_3$	Lead vanadapatate

Locust, N. J., November, 1911.

Art. XIX.—*Optical Resolution of the Saturnian Ring;* by David Todd.

Observational research upon the ring of Saturn may be embraced in ten stages:

(1) Galileo (1564–1642) represented the Saturnian system triform. "*Ultimum (altissimum) planetam tergeminum observavi,*" he announced and he drew the ring as two separate, equal, and lesser spherical bodies on either side of the planetary ball.

(2) Scheiner (1575–1650) connected these two bodies with the planet, making it appear like a head with large ears, or a circular plaque with *ansae* (handles) as they were called, and still are.

(3) Riccioli (1598–1671) and Hevelius (1611–1687), with larger and better telescopes, came very near the real ring form and all but guessed the true shape of the puzzling anomaly.

(4) Huygens (1629–95) was the first who divined the ring as such, and he gave a full and accurate description of it as follows: "*Anulo cingitur tenui plano nusquam cohaerente ad eclipticam inclinato.*" His characterization of the ring first explained all the appearances that had baffled his predecessors: how the ring might disappear and reappear, and in about 30 years could pass through a complete cycle of phases, from absolute invisibility to the amplest widening.

(5) Cassini (1625–1712), with a better telescope, showed that the ring had symmetric dark markings on it which divided it into two parts though unequal in breadth, the inner one the brighter and broader.

(6) Encke (1791–1865) discovered a similar division of the outer ring into two parts, though he found it impossible to trace the dark dividing line all the way round. In fact, it is often invisible at the present day.

(7) Bond (1789–1859) and Dawes (1799–1868) discovered a broad, dusky ring inside the inner Huygenian ring, and seemingly joined to its inner edge.

(8) Barnard (1857–), by observing with the Lick telescope the transit of Japetus through the shadow of ball and rings, found the satellite readily visible in passing the crape ring, fainter by the bright ring, while it disappeared completely in the shadow of the ball.

(9) Keeler (1857–1900) photographed the spectrum of the ring, and measured the displacement in spectral lines of the inner and outer edge of the bright ring. This displacement he found exactly what it should be if the ring were not solid, but made up of clouds of particles revolving round Saturn, as shoals of satellites in full accord with the Keplerian harmonic law. The ring might still, however, be gaseous.

It only remained to visualize the separate particles of which the ring is composed. There are many telescopes powerful enough to make this observation possible; and the highly unfa-

vorable conditions of our lower atmosphere are alone responsible for failure hitherto to resolve the ring into its component satellites.

The writer has for many years observed Saturn at every favorable opportunity, and with the highest magnifying powers that the conditions of atmosphere would admit. In 1905, when the 18-inch Clark glass was first mounted at Amherst, the ring was too much foreshortened and the inner regions of the *ansae* too restricted in area. In 1907 when the glass was taken to Chile for photographing Mars, the ring was passing its period of edgewise visibility: the desert seeing, however, was most of the time superb, and resolution of the ring would have been relatively easy, from our station at Alianza in the foothills of the Andes, had the presentation of the ring been favorable.

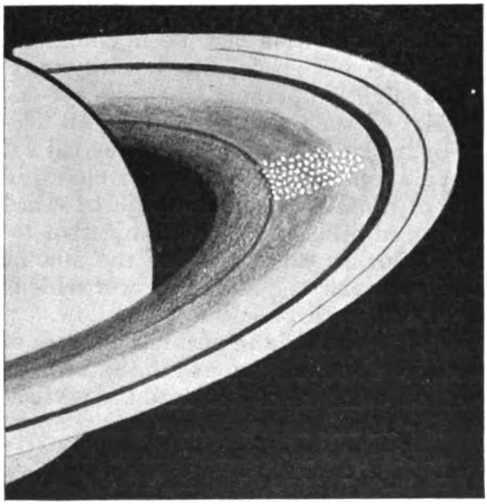
Since remounting the telescope at Amherst, every opportunity of exceptional definition has been embraced. Furthermore, the objective has been fitted with an exterior iris diaphragm, conveniently operated from the eye-end; and the absolute necessity of such an appliance in all telescopic work requiring fine definition has been proved beyond a doubt. The pupil of the eye automatically opens and closes, in adaptation to the strength of illumination of the object toward which it is turned; and the addition of a great objective to the optical system requires further adaptation of the amount of light it gathers to that particular magnifying power which the special condition of the always turbulent air will allow.

The weather conditions of the peculiar autumn of 1911 gave many opportunities when resolution of the Saturnian ring near its extremities was suspected; but not until the perfectly quiescent nights of October 28 and 29 was there a near approach to that serenity and entire atmospheric calm which I had before experienced but twice: on the summit of Fuji-san in 1887, and in the desert of Tarapacá in northern Chile twenty years later. The power on this occasion was pushed nearer to the limit than I had ever found it possible to do before at Amherst. The sky, too, was absolutely clear of haze, so that a power of 950 gave only very slightly scattered illumination in the field. In moments of best definition a power of 1400 was found to perform satisfactorily with an aperture of 16 inches.

Near the extremities of the inner bright ring there was a lenticular shading, as drawn by Proctor (1837–88), and less pronouncedly by Barnard; and it was in this especial region that, in moments of the best vision, a certain sparkling flocculence was more or less steadily glimpsed; scintillant much as fine snowflakes sun-illumined at the close of a storm. There was no longer in the writer's mind any doubt that the separate component satellites of the ring had been seen, at least in that

part of the inner Huygenian ring which is adjacent to the extremities of its major axis. The degree of amplification seemed too great for resolution of the dusky ring; in fact, with the highest powers it was very difficult to discern this ring at all. The accompanying sketch of the critical region of the planet is a crude attempt to show approximately the area of the resolution in the following *ansa*, though it was by no means so regular either in character or outline as the engraver has represented it. It should be viewed not less than eight feet from the eye.

Through November, December, and early January every favorable opportunity of observing Saturn was embraced, but at no time did the seeing approach the excellence of late Octo-



Following Ansa of Saturn, Oct. 28, 29, 1911.

ber. Usual winter conditions having evidently set in for a permanency, no further opportunity for verification of the resolution appeared likely to offer during the current presentation. A Latin dispatch was therefore framed, with the assistance of my colleague, Dr. Houghton, and forwarded to Sir David Gill, as follows: *Saturni anulorum clarorum exteriorumque axium maiorum prope extrema, me adiuvantibus validissimis telescopiis, quandam flocculentiam scintillantem observavi, quam oculorum dissipationem anuli esse interpretatus sum.*

By a like fatality that rendered Schiaparelli's *canali* into canals, *oculorum dissipatio* became, not optical *resolution*, its true English equivalent, but *dissipation*,—a simple transliteration which implied a breaking up or dissolution of the ring: an idea wholly foreign to the writer, who is no friend o catastrophic theories of the Saturnian ring.

Amherst College Observatory, January 16, 1912.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Canadium, an Alleged New Element of the Platinum Group.*—The announcement is made by A. G. French, a metallurgist of the Nelson district in British Columbia, that he has discovered a new noble metal and has named it canadium in honor of the Dominion. It was found in the dike rocks in the Nelson district, occurring associated with platinum metals in quantities from a few pennyweights to three ounces per ton. It occurs pure in semi-crystalline grains, and in short rods about half a millimeter in length and one-tenth of a millimeter in thickness. It has been found also in the form of scales in platinum-bearing ores. These particles, which have a bluish-white color, contain the metal alloyed with a volatile substance which may be osmium, as it is dispelled by the blowpipe, leaving a brilliant bead of "canadium." The new metal is not platinum, ruthenium, palladium, nor osmium, as it is much softer than these and is more fusible, being quite readily melted by the blowpipe. It is not oxidized by long heating in the oxidizing blowpipe flame. It is soluble in nitric and hydrochloric acids, and in mixtures of the two acids without residue, and the solution in nitric acid gives no precipitate with sodium chloride solution. Therefore it is not silver, a fact which is also indicated by the circumstance that the metal is not blackened by alkaline sulphides. The metal is not colored by tincture of iodine, and the nitrate solution gives no precipitate with potassium iodide. These tests show that it is not palladium. Its melting-point is somewhat lower than that of gold or silver, and very much lower than that of palladium. It is electro-negative to silver. When it is alloyed with gold and silver in "parting" proportions, dilute nitric acid dissolves the silver first and then the new element, leaving gold and the usual brown form, but if the action is stopped when the silver is all dissolved, and the dark residue is then dried and pressed with a knife-blade, the color is a most beautiful and brilliant white. The new metal may then be dissolved by further treatment with nitric acid, precipitated by zinc, and cupelled with lead to a white bead which is not colored by alkaline sulphides.

If the description given is accurate, a new metal would seem to be indicated, and a more thorough chemical examination on a larger scale, which is intended to be made soon, will be awaited with much interest.—*Chem. News*, civ, 283. H. L. W.

2. *The Alleged Complexity of Tellurium.*—The anomalous position of the atomic weight of tellurium in the Periodic System has led to many attempts in recent years to separate it into elements of higher and lower atomic weights, and many such efforts have led to negative results. However, some recent work has indicated that the fractional decomposition of tellurium tetrachloride

by means of hot water gave a product which showed a lower atomic weight for tellurium than the one usually accepted. In fact an atomic weight as low as 124·32 was obtained by Flint from such fractionated material in one case, in place of the usual atomic weight, 127·5. Since Baker and Bennett had previously failed to find any change in tellurium by this same method, as well as by six other methods, HARCOURT and BAKER have repeated the work. Starting with some very pure telluric acid, they made four fractional precipitations in series from solutions of the tetrachloride by pouring them into boiling water. The tellurium of the final product was carefully purified and its atomic weight was determined by converting it into the tetrabromide. Five results gave the numbers 127·55, 127·55, 127·53, 127·53, and 127·53, while determinations on material similarly purified, but without the attempted fractionation, gave a mean result of 127·53. Since the results showed no evidence of the slightest change by means of the fractional precipitation, the operation was not carried further. The authors believe that the low results previously mentioned were due to contamination of the dioxide with trioxide, which was shown to give a precipitate with an orange color. It is evident, at all events, that no fractionation of tellurium into different elements has as yet been effected.—*Chem. News*, civ, 260.

H. L. W.

3. *A New Quantitative Separation of Iron from Manganese.*—J. A. SANCHEZ has found that when pyridine is added to a neutral or slightly acid solution of ferric and manganous salts, all the iron is precipitated as hydroxide, while the manganese remains in solution. It is stated that in this way it is possible to separate 0·0005 g. of manganese from 1 g. of iron. Neutralization of nearly all the free acid by caustic soda or potash, adding pyridine, boiling for 10 minutes, and washing the precipitate first with hot water saturated with pyridine, then with hot water alone, are recommended. No test analyses are given, nor is any statement made in regard to the behavior of nickel and cobalt in the separation, but it is stated that zinc goes partly into the precipitate and partly into solution.—*Bulletin*, ix, 880. H. L. W.

4. *Famous Chemists;* by E. ROBERTS. 12mo, pp. 247. London and New York, 1911 (The Macmillan Company).—The object of this little book is to give an account of the chief work of the most famous chemists, and to indicate briefly the part played by each in the development of the science. The subjects treated are Stahl, Boyle, Black, Cavendish, Priestly, Scheele, Lavoisier, Berthollet, Dalton, Davy, Gay-Lussac, Berzelius, Faraday, Dumas, Wöhler, Liebig, Graham, Bunsen, Hofmann, Pasteur, Williamson, Frankland, Kekulé, Mendeleeff, Perkin, and Victor Meyer. The essays include the important biographical facts as well as the principal achievements of these heroes of chemistry. The articles are clear, concise, and well written, and the book will be very useful to those who wish to obtain an outline of the development of modern chemistry. H. L. W.

5. *Quantitative Chemical Analysis;* by CLOWES and COLEMAN. 8vo, pp. 565. Philadelphia, 1911 (P. Blakiston's Son & Co.). This text-book is so well known and widely used, both in Great Britain, the place of its origin, and in the United States, that the appearance of the present ninth edition requires no comment except the statement that the text of the much improved eighth edition, which appeared two years ago, has been carefully revised with the result that some additions and improvements have been made, and errors have been corrected. H. L. W.

6. *Photometric Paddle-Wheels.* — JAMES R. MILNE has recently described a new form of rotating photometric sector similar to a paddle-wheel in appearance, and consisting, in one form, of two flat, triangular vanes fixed to the shaft of a motor by which they are rotated. The amount of light interrupted depends on the azimuth of the base, which angular measurement can be made with a high degree of accuracy. The author gives a mathematical discussion of this new type of apparatus, in which are deduced formulæ for the intensities of the light transmitted under different conditions, and for the greatest width of the beam of light that can be employed; and a graphical tabulation of the values of these formulæ in different cases is provided. The mounting and details of an actual instrument are also described, together with an additional mechanism for the purpose of automatically recording the photometric measurements obtained.—*Proc. Roy. Soc. Edinburgh*, vol. xxxi, pp. 655–683.

7. *A Text-Book of Physics;* by LOUIS BEVIER SPINNEY. Pp. xi, 605. New York, 1911 (The Macmillan Co.).—This volume is designed primarily for use as a text in courses offered to engineering and technical students. Hence, special emphasis is laid on the practical aspects of the subject. Illustrations of physical laws are drawn as far as possible from familiar phenomena, and physical principles are exemplified by numerous important applications. Particular emphasis is placed upon the subject of Mechanics. Also, it is expected that the book will be used as a basis for class-room work and that it will be supplemented by a course of experimentally illustrated lectures and suitable laboratory exercises. The text is up to date and includes, of course, a discussion of ionization and radio-activity. A knowledge of plane trigonometry and elementary chemistry is assumed. The figures are large, well-drawn and interesting, and Gothic type is used for emphasis. 325 problems for solution are distributed throughout the volume.

As regards minor details the book possesses both satisfactory and unsatisfactory characteristics. For instance, on page 26 an acceleration is given as "2 miles per hour per minute," which is very helpful to students who find difficulty in grasping the full meaning of 2 miles per sec. per sec. On the other hand, the term moment of inertia is introduced symbolically on page 39, but its physical significance is first brought out on page 81. H. S. U.

8. *Tables of Physical and Chemical Constants and some Mathematical Functions;* by G. W. C. KAYE and T. H. LABY. Pp. vi, 153. London, 1911 (Longmans, Green, & Co.).—The need of a comparatively small volume of up-to-date tables of physical and chemical constants has been felt for some time, not only by the authors but also by the writer of this notice. Hence it seems fair to assume that this volume will appeal strongly to others who are engaged either in giving instruction to laboratory classes or in original investigations.

The material has been wisely selected and the manner of presentation is excellent. Thus, in addition to the data incorporated in the older reference books of this type, fifteen pages are devoted to ionization and radio-activity. Also a table of e^{-x} is appended. The utility of the volume is enhanced by the insertion, in the case of many of the sections, of a brief résumé containing references to such books and original papers as may be profitably consulted. The authors say in their preface: "Every effort has been made to keep the material up to date; . . . . . ."

All numbers, units, etc., deserving special emphasis are printed in bold-faced type and an index to the pages is given. The book is bound in a flexible cover, so that it will lie open flat or lend itself to any other convenient position of holding.

In conclusion, the present writer desires to state explicitly that the book appeals very strongly to him and he hopes that many other instructors and investigators will not only give the tables practical trial, but will also take advantage of the prefatory invitation of the authors, namely, ". . . . . we shall be very glad to receive suggestions and to be informed of any mistakes which, despite every care, have eluded us." If this is done, a very valuable set of convenient and reliable tables may be produced in the course of a few years. H. S. U.

9. *Elektrochemische Umformer [Galvanische Elemente];* von JOHANNES ZACHARIAS. Pp. xii, 262; 122 figures. Vienna and Leipzig, 1911 (A. Hartleben).—The author considers the customary classification of cells, as primary and secondary elements, to be unsatisfactory and illogical, and hence he bases all of his discussions on the use, performance and manner of working or discharging cells. Consequently the title, "Electrochemical Transformers," has been selected "to comprise all devices which serve to transform chemical energy into electrical work by the wet process."

Special attention is given to batteries for furnishing strong currents and to the so-called "earth cells." Also, a special section is devoted to a detailed account of pocket lamps. Accumulators or secondary batteries are not given prominence. Numerous tables and curves are distributed throughout the text to illustrate the behavior of different types of cells under almost every conceivable condition of activity.

The author maintains a practical point of view, so that the book should appeal primarily to those who desire to select a battery which is most suitable for fulfilling specified working conditions. H. S. U.

10. *Die Neue Welt der Flüssigen Kristalle;* by O. LEHMANN. 8vo, pp. 388. Leipzig, 1911 (Akademische Verlagsgesellschaft).—To anyone acquainted only with ordinary crystals, the idea of a liquid crystal—a substance which, if deformed, will flow back into crystalline shape—is hard to grasp. Professor Lehman is the discoverer of this class of substances and has done more work in the field than has any other investigator, so he speaks with authority.

Rather curiously, liquid crystals are hardly mentioned in the first hundred and fifty pages of the book. Instead various other subjects are considered which are often only remotely connected with liquid crystals but which have been investigated by the author at one time or another. For instance, there is an account of the author's discovery of the transition temperature and a description of his crystallization miscroscope. The description of liquid crystals, their preparation and properties, occupies about a hundred pages and appears to be very well presented. There are chapters following which it is difficult to account for in a book of this character—chapters, for instance, on the growth of living things, latent life and soul (latentes Leben und Seele), atom souls (Atomseelen), and muscle power (Muskelkraft).

Taken as a whole, the book is an account of the author's scientific work rather than an account of liquid crystals. The part devoted to the latter appears to be very good. The rest may be excellent, but it is on subjects having little to do with the title page. H. W. F.

II. GEOLOGY AND NATURAL HISTORY.

1. *Thirty-second Annual Report of the United States Geological Survey.* GEORGE OTIS SMITH, Director. Pp. 143; 2 maps. Washington, 1911.—The operations of the Survey for the year 1910–11 continue the gratifying record made in previous years. When the value and amount of work is compared with the aggregate cost ($1,477,440) it seems evident that no governmental bureau is yielding greater returns in proportion to the amount expended. It is satisfactory to note that the Survey is becoming each year more generally useful to the various departments involved with governmental administration. More than any other bureau it stands as a scientific adviser to the government in all matters relating to the development of natural resources. In the development of plans for wiser distribution and control of public lands, water supply, irrigation, coal, oil, and ore deposits, it is essential that some bureau possessing high skill and freedom from political control should be given charge; and it speaks well for the reputation of the Survey that this particular bureau should be relied upon to furnish accurate and unbiased information as the basis for legislative enactments. Because of the changes in the Department of the Interior which have placed

the administration of public lands on a more scientific basis, the work of the Land Classification Board has become an important feature of the Survey's activity, and under the direction of W. C. Mendenhall, the present chairman, is increasing in amount and in accuracy. Fortunately the past work of the Survey has been done in such a manner that extensive records and studies covering a long term of years are available. Without these data public land legislation would be necessarily unsatisfactory.

The general value of the Survey to the country is indicated by the growing demand for its publications. During the year under consideration the number of reports and maps issued reached the enormous total of 1,208,797 (488,930 books, 34,117 folios, 684,129 maps). Of this amount half a million maps were sold, an increase of 15 per cent over the previous years. The demand in some instances is so great that second editions were required of five Bulletins, twelve Water-Supply Papers, and of the Mineral Resources of the United States.

An examination of the outline map showing the area covered by topographic surveys indicates substantial progress during the year. The maps of six states have been completed; 50 per cent of nine other states has been covered; and only five states show less than 10 per cent of their area represented by maps.

The organization of the Bureau of Mines, relieving the Survey of a portion of its economic work, which was only remotely related to it, seems on the whole to have been a satisfactory arrangement; it allows for the enlargement of its work along scientific lines as well as of basal studies in conservation.

It is an interesting indication of the growth of interest in scientific studies and the appreciation of expert scientific knowledge as a basis of legislation that various new bureaus have from time to time been created from sections in the Survey, without decreasing the staff or scope of the work of the parent organization.

H. E. G.

2. *The Granites of Connecticut;* by T. Nelson Dale and H. E. Gregory. Bull. 484, U. S. Geol. Survey, pp. 137, pl. vi. Washington, 1911.—This is a continuation of the very useful reports on the granite industry in the eastern states published in recent years by the Survey. The subject is treated both from the scientific and economic standpoint, but in such a manner as to make the more purely scientific parts quite intelligible to the general reader.

In part one, which is devoted to the scientific portion of the work, Professor Gregory first treats in a broad, concise way of the salient features of the geology of the state with especial reference to the origin, nature, and classification of the rocks, the distribution of the bodies of granite being shown on a colored geologic map on the scale of 1–500,000. Professor Dale follows with a discussion of various features of the granites, such as their structure, rock variations, weathering and discoloration. The treatment of rift and grain and of sheeting is interesting, though

no new views are advanced, but the author suggests that the dome structure may, perhaps, be due to anticlinal arches in the strata that originally overlaid the granites.

The second part of the work, by Dale, is devoted to a description of the various quarries in the state and to their products. In many instances their location is shown by small maps and the geologic features are described in detail with the aid of diagrams. In nearly all cases the result of a study of the rocks in thin section are briefly given, and where available, chemical analyses are added.

While the main value of the work is on the economic side and it should prove itself technically useful to those engaged in the industry, there is nevertheless much of interest and importance to the geologist and petrographer that is not merely local, but general, in its application. L. V. P.

3. *The Mount McKinley Region, Alaska;* by ALFRED H. BROOKS. *With Descriptions of the Igneous Rocks and of the Bonnifield and Kantishna Districts;* by L. M. PRINDLE. Prof. Paper 70, U. S. Geol. Surv., 4°, pp. 234, pls. 18, 3 maps. Washington, 1911.—In his preface Mr. Brooks, who has long been known for his explorations and pioneer geologic work in Alaska, states that the object of the volume is to give to geologists an epitome of its stratigraphy, structure, and geologic history, and to furnish the prospector with a concise summary of present knowledge of its mineral wealth. Available information regarding the climate, vegetation, agricultural land, wild animals, and means of communication is added for the benefit of intending hunters and settlers. It would be impossible in a brief notice to give any adequate account of the large amount of information which this volume contains in succinct form. It represents a compendium of the labors in the field of a number of workers, chief of whom has been the senior author. The results of the reconnaissances here given will be of great value in the future when more detailed work is undertaken. L. V. P.

4. *Bulletin of the Seismological Society of America.*—The Fourth number of volume I, recently issued, contains among other articles, one on *the California earthquake of July 1, 1911*, by E. C. TEMPLETON. The shock, although not to be compared with that of 1906, was the most severe that has been felt since then, and was felt over an area whose maximum dimension was about four hundred miles, extending from Sacramento to Los Angeles. It was most severe in the region of San Francisco Bay. The shock came without preliminary tremor, and consisted of "two rather distinct periods of vibration, of which the first, with a duration of between five and eight seconds, was the more intense. After a lull of about five seconds came the second period of vibration, with a duration of about five seconds. The shock was accompanied by a dull, rumbling sound, described as similar to the roar of a distant railway train, the sound preceding the shock by two or three seconds." . . . "The maximum intensity occurred

in the vicinity of Coyote, a small town built on the alluvial floor of Santa Clara Valley, twelve miles southeast of San Jose. The intensity throughout the hills between Coyote and Mt. Hamilton, while apparently not as great as it was near Coyote itself, was the greatest reached at any place where the immediately underlying formation does not consist of unconsolidated, filled-in material. The time of the shock at Lick Observatory on Mt. Hamilton is the earliest reliable time reported. Coupled with the fact that the earthquake materially increased the flow of several streams near Mt. Hamilton, these facts seem to indicate that the epicenter was in the region between Coyote and Mt. Hamilton. The movement probably occurred at a considerable depth, with the displacement entirely taken up by the overlying material, leaving no trace or rift on the surface."

Some post-Glacial faults near Banning, Ontario, are described by A. C. Lawson. They occur in a region of marked stability, and are found to exist on the glaciated surface of Archean rocks. The chief facts stated in regard to them are as follows: "The glacial striæ are constant in direction over this surface, and their course is N. 20° E. This glaciated surface is dislocated by a series of reverse or overthrust faults. The fault-plane in most of these is coincident with the cleavage of the slates, and since this dips to the north the result is a series of southerly facing and overhanging scarps, inclined to the horizon at 65°. The edge or crest of the up-thrust block is thus rather acute, being about 25°, and this acute edge is usually perfectly sharp and unworn except for artificial breaks. The reëntrant angle at the base of the scarp, where it meets the horizontal surface of the next lower block to the south, is equally sharp. In no case could any fault breccia or gouge be detected even on a microscopic scale; nor was any well-defined slickensiding observable, although in some cases the surface of the scarp appeared to be smoother than the ordinary cleavage face and even to have a faint polish.

"In every case observed the movement on the faults appeared to be in the direction of the dip, or to have no horizontal component except that normal to the strike. This could be determined by observing the displacement of particular striæ or grooves. On the up-thrust block the striæ, which make an angle of 61° with the strike of the faults, extend out to the very brink of the scarp, and on the adjacent block to the south the striæ pass in under the overhanging scarp and abut against its base. These fault scarps are small but numerous. The highest one measured 3¾ inches vertically, and the others range down to one-eighth of an inch in height. In a distance of 66 feet across the strike twenty-four scarps were counted, and as the faulted surface passed beneath the drift on both sides of this, there is every reason to suppose that there are many more than could be observed."

Similar faults have been described by other authors, but it seems doubtful whether they are to be referred properly to oro-

genic force. The author states that: "The stresses which gave rise to those faults may possibly be very superficial and in no way connected with those deeper seated forces which deform the earth's crust in a large way. It is at least noteworthy that we have in these cases to deal with a peculiar type of faulting which is almost wholly confined, so far as our knowledge goes, to slatey and shaley rocks. The close spacing of the faults, the distribution of the movement, the small amount of overthrust in each particular fault, and their confinement to soft, relatively plastic rocks, suggest that they are perhaps due to stresses connected with a volume change near the surface of the rocks concerned."

5. *Atlas Photographique des Formes du Relief Terrestre*; par J. BRUNHES, E. CHAIX, EMM. DE MARTONNE. Geneva (Éditeurs, Fred. Boissonnas et Cie.).—In this Journal for April, 1911, the plan adopted by the Geographical Congress at Geneva for the publication of an Atlas of terrestrial relief-forms was explained in detail. This plan originated in 1907, when M. E. Chaix proposed the publication of an "Atlas de l'Érosion," in which M. J. Brunhes later agreed to coöperate. In 1908 the ninth International Congress of Geography took the matter up and the scheme which has now taken shape was developed. The specimen number, which has recently been distributed, is gratifying as showing the admirable way in which the promises of the prospectus have been fulfilled. Eight plates are here given, each with the text required to explain the views. One of these is of the Grand Combin, showing the forms produced by mechanical disintegration and by glacial influences; another of the Ravin de Théus illustrates the elementary forms of erosion by streams of water; another of James Peak, Colorado, exhibits the subdued forms of a high mountain modified by glacial action; still another gives two striking views of desert dunes at Taghit in southern Algeria. All the plates are reproduced from excellent photographs with striking fidelity. A special sheet gives in detail the classification of the forms to be illustrated in the complete work; there are nine general types, and each of these is more or less minutely subdivided. The value of the work as a whole to geographers, geologists, and the intelligent public at large can hardly be overestimated, and it is not to be doubted that the 300 subscribers will be soon obtained who are needed to make the publication possible at a moderate price. Circulars and other information may be obtained from the executive committee: Prof. J. Brunhes, Fribourg, Switzerland; Prof. E. Chaix, 23 Ave. du Mail, Geneva, and Prof. E. de Martonne, 248 Bd. Raspail, Paris.

6. *New Zealand Botanical Notes*, by B. C. ASTON. These include: (1) Botanical Notes made on a Journey across the Tararuas, Trans. N. Z. Inst., Vol. XLII, 25 pages, 1 map, 7 plates, 1909. (2) List of Phanerogamic Plants indigenous in the Wellington Province. Ibid, Vol. XLIII, pp. 22, sketch map, 1910. (3) Some effects of Imported Animals on the Indigenous Vegetation. Read before Wellington Philosophical Society, May 10th,

1911.—These render available existing data and add materially to our knowledge of the interesting flora of the South Temperate Zone. The collections made in the Tararua Mountains are from a district not previously visited by a naturalist, and furnish new data regarding distribution and ecological relations. The illustrations are unusually good and pertinent. H. E. G.

7. *Fungous Diseases of Plants, with chapters on Physiology, Culture Methods and Technique;* by BENJAMIN M. DUGGAR. Pp. xii + 508, with 240 text-figures. New York and Boston, 1911 (Ginn & Company).—The majority of American works on parasitic fungi have dealt primarily or exclusively with the fungi themselves, rather than with their host plants. Professor Duggar's book, which forms a volume of the Country Life Education Series, is a notable exception to this rule and lays special emphasis on the host plants, describing clearly the changes which they undergo through the presence of the parasites and calling attention to methods by which further infection can be prevented or controlled, After a series of chapters devoted to culture methods and technique, the diseases are taken up in representative types arranged according to the systematic position of the parasites, the Myxomycetes and Bacteria being considered first and then the Phycomycetes, Ascomycetes and Basidiomycetes. In most cases the parasites selected for description are those which attack cultivated plants or plants which are otherwise of economic interest. The illustrations, many of which are reproduced from photographs, form an excellent feature of the book. A. W. E.

8. *Practical Botany;* by JOSEPH Y. BERGEN and OTIS W. CALDWELL. Pp. vii + 545 with 388 text-figures. New York and Boston, 1911 (Ginn & Company).—Professor Bergen's elementary text-books of botany have long been recognized by teachers as valuable and practicable adjuncts to their work. The present volume, which maintains the usual high standard, is written in response to the demand for text-books which shall emphasize the connection between science and daily life. It gives the essential facts regarding the structure and functions of plants, but also shows how they play a part in agriculture, in the spread of disease, and in yielding products of economic significance. Chapters on ecology and on the geographical distribution of plants are likewise included. The illustrations are largely new and are remarkably clear and satisfactory. A. W. E.

9. *A Practical Course in Botany, with especial reference to its bearings on Agriculture, Economics, and Sanitation;* by E. F. ANDREWS. Pp. ix + 374, with 15 plates and 511 text-figures. New York, Cincinnati, and Chicago, 1911 (American Book Company).—The present text-book is written particularly for schools which are not provided with a full laboratory outfit. Microscopic structure, therefore, receives but a limited amount of attention, and most of the work suggested can be carried on by the direct examination of material in the class room or in the field. With the exception of the concluding chapter, which gives

a brief description of cryptogams, the book is almost entirely devoted to flowering plants, and the subjects treated are taken up in the following order: the seed, germination and growth, the root, the stem, buds and branches, the leaf, the flower, fruits, the response of the plant to its surroundings. Practical questions are interspersed throughout, and considerable attention is given to topics of economic importance. The illustrations are profuse and well selected. A. W. E.

III. Miscellaneous Scientific Intelligence.

1. *Report of the Secretary of the Smithsonian Institution for the Year ending June 30, 1911.* Pp. 91. Washington, 1911.—The Smithsonian Institution is so remarkably efficient, not only in its general activity, but also in the variety of spheres in which it works, that the annual report of the Secretary, Dr. Charles D. Walcott, always contains much that is of general interest. One point to be noted is that a sum of $40,000 has been bequeathed to the Institution by George W. Poore, of Lowell, Massachusetts, who died in December, 1910. The income is to be added to the principal until a total of $250,000 has been reached, when the income of the fund so established is to be used for the purposes for which the Institution was created. This clearly indicates an appreciation on the part of the public of the work which the Smithsonian is doing, and gives reason to hope for further bequests in the future. A trust fund, yielding an income of $12,000, was earlier established by Mrs. E. H. Harriman, to be devoted particularly to the study of American mammals and other animals. Of the special explorations and researches is to be mentioned, first, the remarkable work of the Secretary, at the trilobite locality on the slope of Mt. Stephen, near the Canadian Pacific Railroad. The exhaustive biological survey of the Panama Canal zone is now established on a solid basis, through the contribution of funds from outside. The Rainey expedition in Africa, the bird studies in the Aleutian Islands in the Behring Sea, and the anthropological researches of Dr. Hrdlička in Peru, are other lines along which the work of the Institution has been extended.

As regards publications, some 200,000 copies of various issues have been distributed through the past year, while the Department of International Exchanges has handled some 229,000 packages, weighing 561,000 pounds. The structural work on the new National Museum was completed on June 20, 1911, just six years after the excavations for the foundations were commenced. The collections have been largely removed to the new building and reinstalled, while 200,000 specimens of animals and plants have been added.

The work of the Astrophysical Observatory, under Mr. C. G. Abbot, is detailed in Appendix V, from which the following

summary is quoted : "The year has been distinguished by a successful expedition to Mount Whitney. The results obtained there confirm the view that determinations of the intensity of the solar radiation outside the earth's atmosphere by the spectrobolometric method of high and low sun observation are not dependent on the observer's altitude above sea level, provided the conditions are otherwise good. The Mount Whitney expedition furnished opportunities also for measurements of the brightness of the sky by day and by night, the influence of water vapor on the sun's spectrum, and the distribution of the sun's energy spectrum outside the atmosphere. Solar-constant observations and closely related researches were continued daily at Mount Wilson until November, 1910, and were taken up again in June, 1911.

Further research tends to confirm the conclusion that the sun's output of radiation varies from day to day in a manner irregular in period and quantity, but roughly running its courses within periods of 5 to 10 days in time and 3 to 10 per cent in amplitude. Assurance seems now complete that this result will be tested in the next fiscal year by long-continued daily observations made simultaneously at two widely separated stations.

Many copies of the silver disk secondary pyrheliometer have been standardized and sent out to observers in this and foreign countries to promote exactly comparable observations of the sun's radiation.

Measurements of the transparency, for long-wave radiation, of columns of air containing known quantities of water vapor have been continued, and promise highly interesting results."

The following has recently been issued: Classified List of Smithsonian Publications available for distribution, January, 1912. Pp. vi, 29.

2. *Report of the Librarian of Congress and Report of the Superintendent of the Library Building and Grounds for the fiscal year ending June 30, 1911.* Pp. 244 ; 5 plates. Washington, 1911.—The Report of the Librarian of Congress, Mr. HERBERT PUTNAM, shows that the expenditures for the past year amounted to $655,000. The appropriations for the coming year are about $50,000 less, chiefly because a smaller amount is needed for the new book-stacks. The gain in number of books is nearly 100,000, making the total about 1,900,000 ; there have been also some 60,000 accessions in the way of maps, music, and prints. It is interesting to note two bequests from abroad, one in 1910 from the late Henry Harrisse, the historian of the period of the Columbian discovery. This includes a full set of his own writings, annotated, with books, maps, and manuscripts on related topics. The other bequest of May, 1911, was from the late Dr. A. B. Meyer, of Dresden, of the letters of Professor F. Blumentritt, concerning certain matters in the Philippines. The articles themselves have not thus far been received. A list is also given of a series of gifts which, although not remarkable as concerning collections of books, show that the Library is becoming rich

through what it receives from donors as well as by what it acquires by purchase and, directly and indirectly, from the Government.

3. *Das Schicksal der Planeten;* by SVANTE ARRHENIUS. Pp. 55. Leipzig, 1911 (Akad. Verlagsges. M. B. H.). — Professor Arrhenius is well known as a writer on cosmogonic subjects and one welcomes this little tract containing a brief exposition of his conclusions concerning the present and future conditions of the inner planets. In reaching his results the author does not confine himself to any one department of physical science: the established facts of astronomy, geology, chemistry, physics, and biology are all brought into service. More particularly, stress is laid on the application of the physiography of the arid parts of the earth's surface in order to explain present conditions on Mars and the Moon.

The appearance of a popular account of more extensive researches elsewhere calls for a criticism of the manner rather than of the matter. In setting forth his views, Professor Arrhenius writes clearly and easily, avoiding involved sentences and qualifying clauses. For this the reader is grateful. It has, however, perhaps caused the author to fall into a too dogmatic statement of his conclusions. The subject is not one on which any large body of scientific men are agreed, and the uninitiated, for whom the publication is apparently intended, may accept as the final results of science what should properly be considered the views of one of its exponents. ERNEST W. BROWN.

4. *The Capture Theory of Cosmical Evolution;* by T. J. J. SEE, F.R.S. 4to, pp. vii, 735. Lynn, Mass., 1910 (Thomas P. Nichols & Son Co.).—This is the second volume of the author's "Researches on the Evolution of the Stellar System." It is elegantly printed and the plates, nearly 100 in number, mostly reproductions of astronomical photographs, are most admirable.

The term "Capture Theory," first used to designate the method of formation of the Jovian family of comets, is taken by Dr. See as the name for his system of cosmogony. The "capture," however, is made possible on a grand scale only by the agency of a resisting medium of cosmic dust which can be supplied where necessary from the vapors of a central body through light pressure. The author pronounces his theory to be incompatible with the Nebular Hypothesis of LaPlace, and constantly refers to the latter as disproved.

It is true that the Nebular Hypothesis has been found insufficient to explain the process of evolution indicated by the structure of many of the nebulæ, and notably the great class of spiral nebulæ, and that tidal evolution as developed by Darwin adds a new chapter to it; but astronomers will hardly agree to relegate it to the category of "creeds outworn" until Dr. See's arguments have been subjected to a rigorous criticism. They will rather still lean to the opinion expressed by Simon Newcomb at the close of his brilliant career that he yet retained "a little incredulity as

to our power, in the present state of science, to reach even a high degree of probability in cosmogony."

The following extract from the publishers' notice of this work is mostly erroneous and quite misleading:

"Since the accompanying standard circular was prepared, in the summer of 1910, Professor See's celebrated discoveries in Cosmogony have been confirmed by many eminent astronomers; so that the Capture Theory has triumphed all along the line. Foremost among these verifications must be ranked Professor E. W. Brown's confirmation of the Capture of Satellites, announced to the American Association for the Advancement of Science at the Minneapolis meeting, December, 1910 (Science, Jan. 20, 1911, p. 93), and more elaborately treated in the Monthly Notices of the Royal Astronomical Society for March, 1911, p. 453. In this paper Professor Brown shows, by an extension of the methods adopted by Professor See, that the asteroids are transferred from beyond Jupiter's orbit to the zone within, and that some of them may become satellites in the process of transition. The captured satellites may move either direct or retrograde, as first announced by Professor See in May, 1909." W. B.

5. *The Teaching of Geometry;* by DAVID EUGENE SMITH, Teachers College, Columbia University. 12mo, pp. v, 339. Boston and New York, 1911 (Ginn & Co.).—This is a clear discussion of the merits of Geometry, of the means for making the subject more attractive and of its relation to the other sciences. The rise of Geometry is outlined, and the evolution of the method of teaching it, and the development of its definitions and assumptions. The mathematical curriculum has been subject of late to such severe attacks by exponents of loose theories of education that the support afforded by such a broad view of the subject is welcome. W. B.

6. *The Hindu-Arabic Numerals;* by D. E. SMITH and L. C. KARPINSKY. 12mo, pp. 160, Boston and New York, 1911 (Ginn & Co.).—A very complete and scholarly treatise on the origin and introduction into Europe of the modern number system. Copious notes and references put the reader in touch with all the important literature of a subject which has an even stronger interest as bearing on the history of civilization than on its mathematical side.

Few stop to think how much of modern progress depends on these labor-saving symbols, and fewer still realize that their general acceptance in the transactions of commerce dates back only four centuries, and that a system of place values struggled for a thousand years to supplant the crude notation of the Romans. Specially interesting in this volume is the chapter on the symbol zero, the invention of which came long after that of the others, which without it were of comparatively little use. The author aptly points out how the production of this crux ot the system was beyond the power of any race but the Hindus,—though to them in complete harmony with the philosophy whose highest good is the Nirvana. W. B.

OBITUARY.

Major CLARENCE E. DUTTON, the eminent geologist, died on January 4 in the seventy-first year of his age: A notice is deferred to a later number.

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VOL. XXXIII. MARCH, 1912.

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THE

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[FOURTH SERIES.]

Art. XX.—*The Mineral Sulphides of Iron*, by E. T. Allen, J. L. Crenshaw, and John Johnston; *with Crystallographic Study*, by Esper S. Larsen.

Introduction.

Application of Chemistry to the problems of ore deposition.—The problems of ore deposition have claimed the attention of geologists for a long time, both for economic and for scientific reasons. The difficult questions as to the origin of ores and the conditions of their genesis have been zealously studied, and with notable success; yet despite the great advances which have been made, no one will question that the scarcity of chemical data has been a serious drawback in the development of the subject. A laboratory investigation of some phases of it involves, indeed, difficulties which are still to be surmounted, but the problems of the temperature ranges within which the minerals have crystallized, the composition of the solutions from which they have come, and the agencies which have precipitated them are in general not only within the bounds of chemical possibility but within the limits of present day methods.

The sulphides of iron.—The sulphide ores from a chemical view-point are of very great interest, and geologically, they are of high importance. The sulphides of iron, in particular, frequently carry paying quantities of gold and nickel, and when [illegible]selves barren, are so frequently associated with other [illegible]ble ores as to hold a place of unusual significance in a [illegible]al consideration of the subject of ore deposition. The [illegible] knowledge of these substances is still very meager. [illegible]es of pyrite and pyrrhotite were made long ago by

Wöhler, Rammelsberg and others, but for the most part by methods which throw little light on their formation in nature.*

Method of study.—In the investigation of this subject the synthetic method has been largely followed, while the most significant properties, reactions and relations of the substances have been studied. Some of the material will be chiefly of chemical interest, but the effort has been made to give special attention to the chemical geology involved and to this end the authors have consulted frequently with several eminent geologists who are specialists in this field. The experience and suggestions of these scientists have been of great value and will be duly acknowledged in the proper place. No optical studies were of course possible on opaque minerals, but crystallographic measurements were made and such microscopic studies as the character of the material admitted of.

I. The disulphides (FeS_2) Pyrite and Marcasite.

Two disulphides of iron are known—pyrite, hard, lustrous, brassy-yellow, of sp. gr. 5·027† at 25°, and crystallizing in the regular system; and marcasite, yellowish grey in color, a little softer than pyrite, of sp. gr. 4·887† at 25° and crystallizing in the orthorhombic system. Both minerals are almost insoluble in hot hydrochloric and dilute sulphuric acids, and both are decomposed by nitric acid. Both are slowly oxidized by free oxygen, the products being, according to conditions, sulphur dioxide and ferrous sulphate, or sulphuric acid and ferrous or ferric sulphate,—sometimes, in fact, sulphuric acid and ferric hydroxide. The conditions have not been investigated completely, though certain definite statements can be made at the present time. In a closed vessel containing air, i. e., with an *excess of sulphide*, the products are sulphur dioxide and ferrous sulphate. When the minerals are heated to 100° in air or ground dry in a mortar, these are the *first* products at least. The sulphur dioxide changes pretty readily, of course, to sulphuric acid. When kept in contact with air and moisture at 75° most of the iron takes the form of ferric hydroxide. Many oxidizing agents, important among which, from a geological standpoint, are ferric sulphate and copper sulphate solutions, change pyrite and marcasite into ferrous sulphate, sulphur and sulphuric acid. In nitric acid of 1·4 sp. gr., powdered pyrite dissolves completely, while marcasite separates sulphur.‡ Both minerals are so nearly

* An exception should be made of the excellent work of Senarmont, Ann. Ch. Phys., xxxii, 129, 1851.

† These specific gravities were determined on very pure natural [illegible] the analyses of which are given on p. 177.

‡ Brush and Penfield's Determinative Mineralogy, 15th ed., p. 2[illegible]

insoluble in water that some statements* regarding their solubility, found in the literature, could only have been made on the basis of experiments in which atmospheric oxygen was not excluded. In all these instances the two minerals behave much alike, though marcasite is always more soluble in any medium and is more readily changed by oxidizing agents.

Formation of iron disulphide in nature.—Geologists appear pretty well agreed that pyrite sometimes crystallizes direct from rock magmas. Pyrite, however, in the great majority of cases, and marcasite in all cases, crystallize from water solutions, though the nature of the process is purely a matter of conjecture. Here a general line of division should be made between the products of *hot* and the products of *cold* solutions. The pyrite of *deep* veins, metamorphic contacts and hot springs, as well as magmas, has been formed by hot solutions, and such solutions never contain strong mineral acids, but are generally if not always alkaline. The pyrite and marcasite of surface veins, on the other hand, are formed from cold solutions which often contain considerable sulphuric acid. We shall find cogent reasons for the conclusion that the chemistry of these two processes is similar, but first let us consider the formation of iron disulphide from surface solutions. Here the geologic hypothesis is that both minerals have been formed by the "reduction" of ferrous sulphate through the agency of organic matter, and indeed, the frequent occurrence of pyrite in coal and its occasional formation on wood gives plausibility to this view. It is plain that the soluble sulphate of iron could not be changed by *simple reduction* to the disulphide, though one might imagine such a reaction as the following equation imperfectly represents:

$7C$ (vegetable matter) $+4FeSO_4 = 2FeCO_3+2FeS_2+5CO_2$. Some experiments have been tried in this laboratory in the hope of "reducing" ferrous sulphate with organic matter, but the results have not been promising. The action of starch and glucose on aqueous solutions at 300° was either slight or nil. On the other hand, the possibilities of hydrogen sulphide are suggestive. Pyrite and marcasite are very often found with simpler sulphides,—those of lead and zinc for example, which may be easily formed by the action of hydrogen sulphide; and furthermore, hydrogen sulphide is a substance widely distributed in nature. Without denying that carbonaceous substances may in some instances be directly active in the formation of pyrite and marcasite, we will proceed to show that both min-
s may be formed through the agency of hydrogen sulphide,
under conditions which doubtless prevail commonly in
re.

e Doelter, Tschermak's Min. Petr. Mitt., N. F. xi, 322, 1890; Neues
., ii, 273, 1894.

Synthesis of iron disulphide.—Apparatus.—All the experiments on the synthesis of pyrite and marcasite were done in sealed tubes, enclosed in steel bombs and heated in resistance furnaces. Several kinds of glass were tried for the tubes, all of which were naturally more or less attacked. The Jena combustion glass and so-called "durax" glass were the only kinds which were found to stand satisfactorily the action of water solutions at the higher temperatures (up to 350°), and even these are pretty rapidly attacked by alkaline solutions. To prevent bursting, the glass tubes were enclosed in heavy steel bombs (see fig. 1), about 80^{cm} in length by 25^{mm} inside and 43^{mm} outside diameter, having thus a thickness of nearly a centimeter. These bombs were closed at one end by an iron plug, *P*, which was welded in. The other end was threaded on the outside and closed with a cap. To insure a tight joint, three concentric grooves about 1^{mm} deep were cut on the open end of the bomb. On this was laid a copper disc, *E*, 3^{mm} thick, on which was placed a steel disc, *D*, 1^{cm} thick. The cap was then screwed down by means of a long steel lever. The steel disc was used to prevent the shearing of the copper disc in screwing down the cap. The joint was lubricated with oil and graphite. The glass tubes were put into the bombs and water was added before closing the latter, so that the pressure on the inside of the glass tubes would be compensated. These bombs will hold satisfactorily up to temperatures of 400°.

FIG. 1.

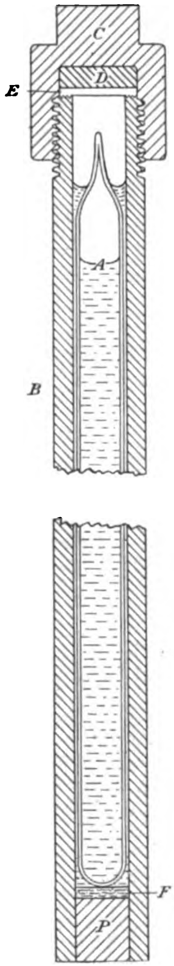

FIG. 1. Bomb used in heating sealed tubes.

Furnaces.—The furnaces in which the bombs were heated were electric resistance furnaces, the coils of which were of nickel wire 0·8^{mm} in diameter, wound on a sheet-iron tube 5^{cm} in diameter, which was first wrapped with asbestos paper. The tube and coil were surrounded by another sheet-iron cylinder 15^{cm} in diameter. The space between the two was fill[ed] with light magnesium oxide. Caps, also of sheet-iron, fit[ted] tightly over both ends of the outside tube, leaving at the upp[er] end (the furnaces were set in an inclined position) a space a[bout]

6^{cm} long for the head of the bomb. A hole about 6^{mm} in diameter through the lower cap admitted the thermo-element. The variation in temperature along the outer wall of the bomb, from a point about 5^{cm} from the lower end to another 20^{cm} farther up, was only about 5°, which is within the error of the direct-reading galvanometer used. This instrument was calibrated within that degree of accuracy, but as none of the temperatures involved had reference to any critical point, it was not considered worth while to measure more accurately.

The action of hydrogen sulphide on ferric salts.—The first action of hydrogen sulphide on ferric salts is, of course, the immediate reduction of the latter and the simultaneous precipitation of sulphur: $Fe_2(SO_4)_3 + H_2S = 2FeSO_4 + H_2SO_4 + S$. No further action has hitherto been noticed, but in a closed vessel where the hydrogen sulphide is prevented from oxidation or escape, a second reaction proceeds, viz: $FeSO_4 + S + H_2S = FeS_2 + H_2SO_4$. At room temperatures, the velocity of this change is very slow, but at 200° it is relatively rapid. The following data prove beyond question the nature of this latter reaction:

3 g. $FeSO_4.7H_2O$ with 0·17 g. H_2SO_4, 0·75 g. sulphur and 100^{cc} water saturated at 0° with H_2S, were sealed up in a glass tube and heated about 2 days at 200°. The product was purified by washing first with water, then digesting with ammonium sulphide to remove excess of sulphur, washing again with water, boiling out with 20 per cent hydrochloric acid, and finally washing in an atmosphere of carbon dioxide and drying in vacuo.

Analysis: Product taken, 0·5044 g. Fe_2O_3 found, 0·3346 g.

	Found	Cal. for FeS_2
Fe	46·44%	46·56%

Another product was formed by heating at 100° for six days the following system: 5 g. $FeSO_4.7H_2O$, 0·5 g. S, 0·17 g. H_2SO_4, and 100^{cc} water saturated at 0° with H_2S. The product was purified in a way similar to the above.

Analysis: Product taken, 0·5003 g. $BaSO_4$ found, 1·9598 g.
" " 0·5006 g. Fe_2O_3 " 0·3295 g.

	Found	Cal. for FeS_2
Fe	46·06%	46·56%
S	53·81	53·44
	99·87	100·00

Both these products were similar to natural marcasite in color and luster. Their crystalline nature was very obvious to the [redacted] eye, though the crystals were small.

Methods of distinguishing pyrite from marcasite.—To distinguish between the disulphides pyrite and marcasite, two methods were employed.

1. Crystals were prepared large enough for goniometric measurement. When hydrogen sulphide and sulphur act directly on a solution of ferrous sulphate, the crystals are in general minute. They increase in size with rise in temperature and several other conditions. One of the most important of these is slow formation. This can be brought about by a simple device (fig. 2). Into a glass tube of about 18^{mm} inside diameter and 65^{cm} in length, is poured through a funnel about 7–10 g. of sodium thiosulphate ($Na_2S_2O_3 . 5H_2O$) dissolved in 30^{cc} water. The ferric salt is contained in another smaller tube which slips into the larger. The small tube has a diameter of 15^{mm} outside and a length of 45^{cm}. It is supported above the thiosulphate solution by a piece of glass tubing a little longer than the depth of the liquid. When the outer tube is sealed, the whole is heated in a bomb as usual. At a temperature of 200°, hydrogen sulphide is slowly generated from the thiosulphate solution, according to the following equation: $Na_2S_2O_3 + H_2O = Na_2SO_4 + H_2S$. By the action of the gas on the ferric salt solution, crystals of measurable size have been repeatedly formed. This scheme, however, could not be satisfactorily used in studying the influence of various conditions on the crystal form. Obviously, not all the crystals of any product could be measured, and it was, of course, a thankless if not impossible task to identify all of them microscopically. Therefore, a quantitative estimation of the two minerals in mixtures could not be made. Besides, the method of synthesis is very slow.

Fig. 2.

Fig. 2. Apparatus for the slow formation of crystals of iron disulphide.

2. Stokes's oxidation method. Some years ago, a chemical method for distinguishing between pyrite and marcasite was worked out by H. N. Stokes.* Since free use of this method has been made, it will be necessary to explain it in some detail. It

* H. N. Stokes, Bull. U. S. Geol. Survey, 1

depends on the difference in behavior between the two minerals toward a solution of ferric sulphate. In both cases the sulphide which is used in *excess* reduces the ferric salt completely to ferrous sulphate, while the mineral itself is oxidized to ferrous sulphate, sulphuric acid and free sulphur. It is in the relative quantities of the products that the difference between pyrite and marcasite shows itself. The reaction may be represented in two stages as follows:

1. $FeS_2 + Fe_2(SO_4)_3 = 3FeSO_4 + 2S$
2. $2S + 6Fe_2(SO_4)_3 + 8H_2O = 12FeSO_4 + 8\,H_2SO_4$

In that portion of the sulphide which takes part in the reaction, the percentage of the sulphur which is oxidized to sulphuric acid depends on conditions, but, *ceteris paribus*, the quantity is much greater for pyrite than for marcasite. In order to distinguish between the two it is therefore necessary to determine what percentage of the sulphur is oxidized to sulphuric acid. Stokes found it most advantageous to use a standard solution (ferric ammonium alum) containing 1 g. of iron and 4·0 g.* free sulphuric acid per liter, and to operate at the boiling temperature. Under these conditions, he found that 60 per cent of the sulphur in pyrite was oxidized, and only 18 per cent of the sulphur in marcasite. Instead of determining *directly* the quantity of free sulphur or sulphuric acid formed in the reaction, Stokes measured the increase in the concentration of ferrous iron in solution. By stochiometrical calculation, for the details of which the original paper must be consulted, he derived the formula, $p = \frac{8{\cdot}33b}{c-a} - 25$, where p is the percentage of sulphur in the reacting sulphide which is oxidized to sulphuric acid, b the *ferrous* iron, c the *total* iron in the solution at the end of the operation, and a the total iron in the *original* solution. There is one point on which Stokes does not express a perfectly clear view, viz: whether the solution at the end of the oxidation should contain any ferric iron or not. As a matter of fact, the reaction, when successful, proceeds to completion, so that all the iron at the end of the operation is ferrous; b and c are consequently identical, and the formula may therefore be simplified to $p = \frac{8{\cdot}33b}{b-a} - 25$. Stokes determined the ferrous iron by direct titration with permanganate. Afterwards he reduced the solution and titrated again so as to determine the *total* iron, ferrous and ferric. This reduction and subsequent titration are evidently superfluous. The process has been improved in several other

* This is our interpretation of Stokes's statement: "16$^{cm^3}$ of 25 per cent —uric acid."

details also. The sulphide has to be very carefully purified. Obviously, any other product which could reduce the solution, or anything like ferrous sulphate or ferric hydroxide which could in any way increase the concentration of the ferrous iron, would interfere with correct conclusions. In the main, Stokes' procedure has been followed, though a new apparatus for

FIG. 3.

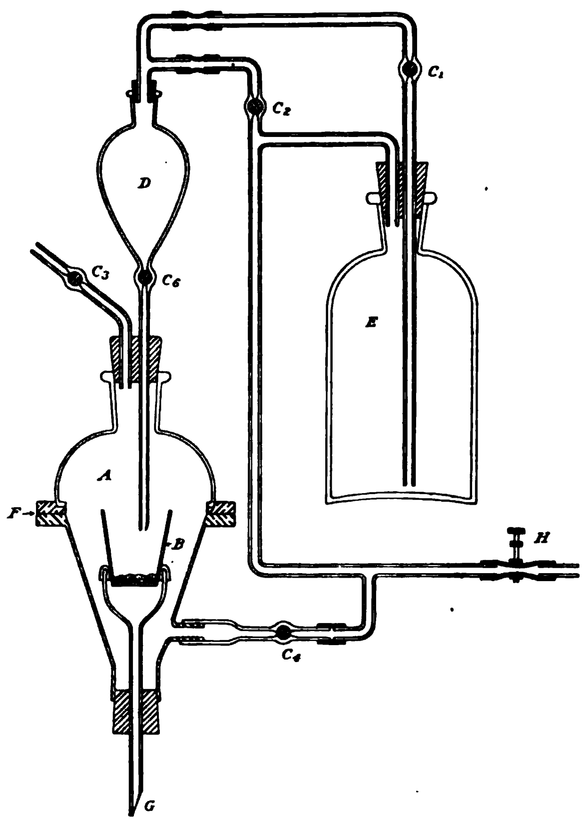

FIG. 3. Apparatus for washing substances out of contact with air.

washing substances out of contact with the air has been devised and used. This apparatus, which is shown in the adjoining figure (fig. 3), has proved of very general utility and convenience. *A* consists of two parts, the lower of brass, the upper of glass cemented into a brass ring. *F* is a ground joint between this ring and another similar ring soldered to

the lower half of the apparatus. In use, this joint is greased with vaseline and the rings are held in place by two spring clamps which are not shown in the figure. The two vessels *D* and *E* are used to contain, respectively, hydrochloric acid and boiled water cooled in carbon dioxide, with which two liquids the ground sulphide in *B* is successively washed. The pressure of the carbon dioxide which enters the apparatus at *H* is sufficient to drive either liquid over into *B* when the proper stop-cocks are opened. *G* opens into a filter flask filled nearly full of water, connected with the water pump. Suction is carefully regulated by a pinch-cock. The apparatus is successively evacuated by the pump and filled with carbon dioxide before using. In drying the material in the vacuum desiccator, instead of using the water pump as Stokes did, we have evacuated by an oil or mercury pump to a fraction of a millimeter. At the end of a half hour the sulphide is not dry but it does not contain enough water to affect the result essentially. In the determination of the ferrous iron, we have employed a weight burette instead of a volume burette.

Results with natural pyrite and marcasite.—The minerals employed were pyrite from Elba* and marcasite from Joplin, Mo. They were purified with great care and then analyzed.† The only impurities found were small quantities of silica and a minute trace of copper in the marcasite.

	Marcasite	Pyrite	Cal. for FeS_2
Fe	46·53	46·49	46·56
S	53·30	53·49	53·44
SiO_2	·20	·04	
	100·03	100·02	100·00

The oxidation coefficients obtained by us were 56 for pyrite and 14 for marcasite, while Stokes found 60 and 18 respectively. The differences have not been entirely accounted for, though we have taken somewhat greater precautions in our work. However, and this is the point to be emphasized, the results of each are probably consistent among themselves.

Determination of the relative quantities of pyrite and marcasite in mixtures.—By grinding together the two minerals in different proportions and then determining the oxidation number for the mixture, Stokes constructed a curve repre-

* In some of the later experiments, a pyrite from Leadville, Col., containing 0·1 per cent copper, was used.

† For the method of analysis, see Allen and Johnston, Zs. anorg. Chem., [illegible]02, 1911.

senting the oxidation coefficients for all possible mixtures. His curve had the form of a eutectic curve with the lowest point at ten per cent, pyrite having an oxidation coefficient of about 15. Fig. 4 shows the curve which we obtained for mixtures of pyrite and marcasite. Careful experiment failed to reveal any mixture which gave a lower oxidation coefficient than pure marcasite. The difficulty of determining accurately the composition of an unknown mixture, by a measurement of

FIG. 4.

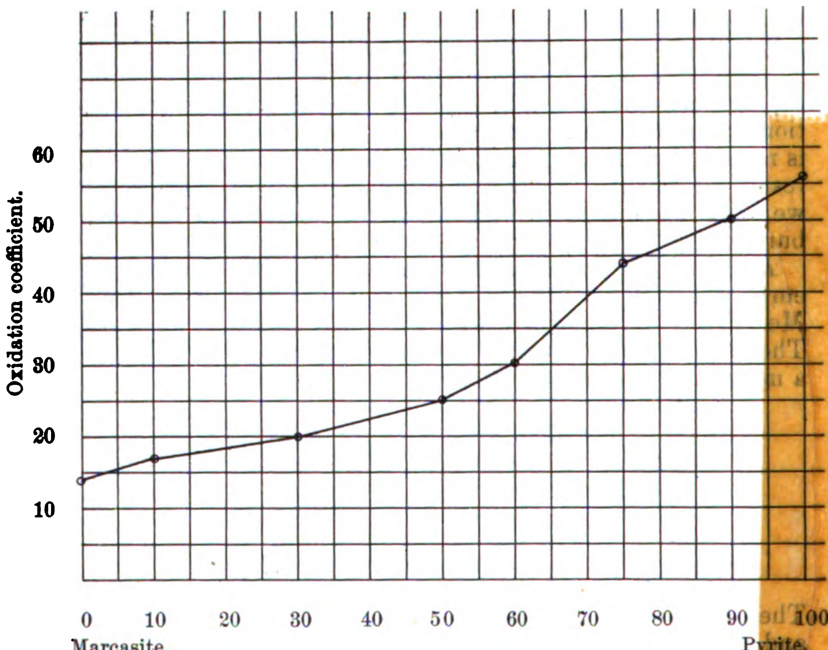

FIG. 4. Curve showing the oxidation coefficients for mixtures of pyrite and marcasite.

the oxidation coefficient, is obvious from the form of the curve; indeed, differences of two to three per cent (of the weight of the mixture) were usually found in duplicate determinations. Yet, though we cannot confirm the statement of Stokes regarding the accuracy of the method, we have found it of great value in studying synthetic products of iron disulphide, the mineral composition of which must otherwise have remained unknown, and have been thus enabled to work out the essential conditions which govern the formation of pyrite or marca-

site. Of course, the method only applies where the substance contains no other reducing agent than pyrite and marcasite. If, therefore, we had present another crystal form of FeS_2, the results would be unreliable. Although both pyrite and marcasite have been repeatedly detected by the microscope in the synthetic products, no evidence of another form has come to light. It is possible that in some instances (which will be pointed out in the proper place) amorphous FeS_2 may have been present. In most cases, however, the crystalline structure was so apparent even to the unaided eye that the presence of any amorphous material was quite unlikely, and this conclusion was only confirmed by the microscopic study.

Marcasite.—Marcasite is the principal product when hydrogen sulphide acts directly on ferric sulphate at 200°.

Exp. 1·5 g. $NH_4Fe(SO_4)_2.12H_2O$ in 100^{cc} water saturated at room temperature with hydrogen sulphide, was sealed up and heated in a bomb for several days at 200°. To insure a sufficient quantity of the product for experiment, three tubes were thus heated under the same conditions. The product was removed, ground fine, purified, and the oxidation number determined. It was found to be 23·6, corresponding to about 43 per cent pyrite.

Influence of free acid on the proportion of marcasite.—The equation $H_2S + Fe_2(SO_4)_3 = S + 2FeSO_4 + H_2SO_4$ shows that sulphuric acid is a product of the reaction in which the marcasite forms, and its concentration evidently increases as the reaction proceeds. It was, therefore, a plausible hypothesis that the concentration of acid influences the crystal form; it seemed possible that the pyrite might have formed in the earlier stages of the process, when the acid was weaker. If this view were correct, a greater initial concentration of acid should result in more marcasite. The hypothesis is proved correct as shown by the results collated in the adjoining table.

TABLE I.

The effect of free H_2SO_4 on the formation of marcasite at 200°.

Taken			Found	
$NH_4Fe(SO_4)_2.12\,H_2O$	Water saturated with H_2S	Free H_2SO_4*	Oxidation number	Per cent pyrite
5 g.	100^{cc}	0·50 g.	23·6	43·
5 g.	100^{cc}	0·57 g.	18·9	25·
5 g.	100^{cc}	0·78 g.	17·0	10·0
5 g.	100^{cc}	1·18 g.	16·5	7·5

* This includes the acid formed in reduction of the ferric iron by hydrogen sulphide.

TABLE II.

Effect of temperature on the formation of marcasite.

Taken					Found	
Temperature	$FeSO_4.7H_2O$	Sulphur	Free H_2SO_4	Water saturated with H_2S at 0°	Oxidation number	Per cent pyrite
300°	5 g.	0·5 g.	0·17 g.	100 cc	29·0	57·5
300°	5 g.	0·5 g.	0·17 g.	100 cc	28·4	56·5
200°	5 g.	0·5 g.	0·17 g.	100 cc	20·7	32·0
100°	5 g.	0·5 g.	0·17 g.	100 cc	16·	6·0
100°	5 g.	0·5 g.	0·17 g.	100 cc	17·2	10·0

Table II shows the influence of temperature on the reaction. Here ferrous sulphate and sulphur, the products of the action of hydrogen sulphide on ferric sulphate, were taken. The quantities of acid used, by inadvertence, were considerably less than intended, but the evidence shows the influence of temperature very plainly. The higher the temperature the greater is the quantity of pyrite formed. A word is here needed on the question of the formation temperature. The furnace was first heated to the required temperature, then the cold bomb containing the tube was introduced. Obviously, the reaction could not take place entirely at one temperature. At the lower temperatures, however, the reaction is very slow, so that the time required for the bomb to reach the temperature of the furnace is not important. When the bombs were heated to 300°, many hours were required to reach the maximum temperature. It would not be worth while, after having shown that the two variables, temperature and acid concentration, both influence the product of this reaction, to study the problem in great detail, but it is interesting to note that the reaction will proceed at ordinary temperatures, and also that pure marcasite may be obtained by a proper combination of the two variables. Thus at 100° the precipitate formed from a solution containing 1·18 per cent of free sulphuric acid gives the oxidation coefficient 14·5 and is therefore pure marcasite. From 2 liters of a solution which contained 3 per cent of hydrous ferrous sulphate and 0·15 per cent of free sulphuric acid, 1 gr. of precipitate was obtained at room temperature in about three weeks. Unfortunately, there was an accident in the determination of the oxidation coefficient of this product, but we can state that it contained less than 10 per cent of pyrite. For every temperature there appears to be a quantity of acid which inhibits the reaction:

$FeSO_4 + H_2S + S = FeS_2 + H_2SO_4$. The quantity is smaller the lower the temperature. It appears to bear no relation to the solubility of the sulphide, for at room temperature this quantity is only a small fraction of 1 per cent. At 200° it lies between 3·5 per cent and 5 per cent; at least this is true for periods of a few weeks.

Crystals of marcasite.—Measurable crystals of marcasite were obtained by the slow action of hydrogen sulphide on ferric sulphate or chloride at several temperatures up to 300° (see p. 174). The general problem of making measurable crystals is one of the most troublesome in synthetic mineralogy. As yet we have no light on the means of controlling the number of nuclei which form in the process of crystallization. In general, the more soluble minerals are obtained in larger crystals. Likewise, larger crystals are obtained from a medium in which they are more soluble. In preparing well-formed marcasite crystals, some unaccountable failures were met with, though generally the products obtained by the method previously described contained a number of crystals which were measurable. The marcasite crystals were like the natural mineral in color and luster and the axial ratio deduced from the angular measurements was $a : b : c = 0{\cdot}7646 : 1 : 1{\cdot}2176$ as compared with $0{\cdot}7580 : 1 : 1{\cdot}2122$ for natural marcasite (Goldschmidt). The striations which marked the crystals agreed with orthorhombic and not with regular symmetry (see III, Crystallographic Study).

*Formation of pyrite.**—While the product of the action of sulphur and hydrogen sulphide on ferrous salts is largely marcasite, the percentage increasing with the quantity of free acid present, pyrite is the principal product where the solution remains neutral or but slightly acid.

Action of hydrogen sulphide on ferric hydroxide.—Freshly precipitated ferric hydroxide is instantly blackened by hydrogen sulphide. The product is a mixture of ferrous sulphide and sulphur, as shown by the following. Freshly precipitated ferric hydroxide was washed free of soluble salts, suspended in water and treated for some time with hydrogen sulphide. A portion of the black amorphous precipitate dissolved in cold dilute acid with evolution of hydrogen sulphide, leaving a residue of amorphous sulphur. Another portion was first digested with ammonium sulphide solution. After filtering

* For former syntheses of pyrite, see Wöhler (Ann., xvii, 260, 1836). Wöhler heated an intimate mixture of Fe_2O_3, S, and NH_4Cl till the NH_4Cl was sublimed. He obtained some small brass yellow tertrahedra and octahedra. Senarmont (loc. cit.) obtained FeS_2 by heating ferrous salt solutions with alkaline polysulphides. Geitner (Ann. 129, 350, 1864) heated metallic iron with a solution of sulphur dioxide to about 200°. His product may have been marcasite. See also Doelter (Zs. Kryst., xi, 30, 1886).

and washing out the excess of reagent, the black residue dissolved without leaving any sulphur behind. The product therefore must have contained free sulphur and could not have been ferric sulphide, Fe_2S_3, though the latter, according to Gedel,* decomposes with dilute acid, giving the same products as the above mixture. A product made by the action of hydrogen sulphide on ferric hydroxide was washed into a glass tube with about 100^{cc} water, saturated with hydrogen sulphide at room temperature, sealed and heated at 140° for seven days. The solution when cooled and opened still smelled strongly of hydrogen sulphide. The product had become quite dense and had a yellowish grey color. It was boiled in hydrochloric acid for some time to dissolve any unchanged ferric hydroxide, or ferrous sulphide, and further purified as usual. The oxidation number was 49, corresponding to 87 per cent of pyrite. The work was repeated with ferric hydroxide† which had been dried at 100° to make it easier to handle. It proved, however, much less susceptible to hydrogen sulphide. It had to be heated repeatedly at 140° with saturated hydrogen sulphide water before the color of the oxide of iron had disappeared entirely. After purification, the product gave the oxidation number 50·4, corresponding to 90 per cent pyrite.

Action of sulphur on pyrrhotite in the presence of a solvent.—The formation of pyrite, just described, is evidently a result of the direct union of sulphur and ferrous sulphide, the first product of the reaction. The hydrogen sulphide water probably acts as a weak solvent. Similarly, the marcasite may be regarded as a product of the addition of sulphur to ferrous sulphide, which forms gradually from solution. The formation of pyrite by the action of sulphur on crystalline pyrrhotite, the relation of which to ferrous sulphide will be shown farther on, proves conclusively that, at a given temperature, it is not the exact nature of the solid phase which reacts with the sulphur, but the composition of the solution in which it forms, that determines whether the product shall be pyrite or marcasite. 2·2 g. pyrrhotite prepared in the laboratory, and 0·8 g. of sulphur were put into a glass tube, to which was added a solution of 0·1 g. of sodium bicarbonate in 100^{cc} water. Before sealing the tube, the solution was partially saturated with hydrogen sulphide. In composition this solution was similar to that of a warm "sulphur" spring, and it served as a solvent for the sulphur, which was gradually absorbed by the pyrrhotite. The tube and its contents were heated for two months at 70°. The product at the end of that time still contained sulphur and undecomposed pyrrhotite. To remove the latter it was boiled

* Jour. für Gasbel., xlviii., pp. 400 and 428, 1905.

† According to Gedel (loc. cit.), $Fe_2O_3.H_2O$ is thus obtained.

for a long time with 20 per cent hydrochloric acid. The residue was dense and brassy-yellow. It was finely ground, purified as usual, and tested by Stokes's method. It gave an oxidation number of 55·1, which corresponds to pure pyrite within the limits of error of the method. To make sure that no mistake had been made in this test, some pure natural pyrite was compared the next day with the same ferric sulphate solution. 100^{cc} of the sulphate solution, after it had been reduced with the synthetic pyrite, required 42·51 g. of permanganate solution. 100^{cc} which had been reduced by natural pyrite took 42·56 g. of the permanganate.

The action of sulphur on pyrrhotite was tried again at 300°, where the reaction was of course much more rapid than at 70°.

Into the tube were put 5 g. powdered pyrrhotite, 1·75 g. sulphur, 0·2 g. $NaHCO_3$, and 100^{cc} water partially saturated with H_2S. The tube was heated four days at 300°. The oxidation number of the purified product was 52·0, corresponding to about 95 per cent pyrite. It is possible that these products contained a very little undecomposed pyrrhotite or perhaps amorphous FeS_2, both of which would have undoubtedly had a similar effect as marcasite in lowering the oxidation number.

TABLE III.

The oxidation numbers of FeS_2 formed from alkali polysulphide solution.

Time	Water	$FeSO_4 . 7H_2O$	Na_2S_2	Sulphur	Temperature	Oxidation number	Pyrite
3 days	100^{cc}	5 g.	plain excess	0·75 g.	300°	54	97%
5 days	100^{cc}	3 g.	plain excess	·75 g.	200°	40·5	71%
7 days	100^{cc}	3 g.	plain excess	·75 g.	100°	26	51%

The action of alkali polysulphides on ferrous salts.—Senarmont* in 1851 showed by analysis that the product of the action of alkali polysulphides on ferrous salts at 180° is FeS_2. The question of the crystal form was not investigated. The black amorphous precipitate† which is obtained at room temperature by the above reaction appears to be a mixture of sulphur and ferrous sulphide, at least it decomposes with dilute acids, giving a residue of amorphous sulphur, while hydrogen sulphide escapes. On heating, disulphide of iron gradually

* Loc. cit.

† Gedel (loc. cit.) claims that this precipitate is Fe_2S_3.

forms, though some of the black precipitate is still unchanged after it has been heated several days at 100° with excess of the polysulphide. The oxidation coefficients of several such products formed at different temperatures, and carefully purified as usual, are given in Table III. Evidently they are not pure pyrite, a result somewhat surprising in view of the previous work; for if we obtain marcasite from the more acid solutions, marcasite with pyrite from those which contain less acid, and pure pyrite from practically neutral solutions, we should naturally expect pure pyrite from alkaline solutions. Further investigation has led us to believe that the products of the alkaline solutions do not contain marcasite, but are mixed with amorphous disulphide. Stokes explained, very plausibly, that the reason why marcasite gave more free sulphur than pyrite when it reacted with ferric sulphate was because it was more soluble; *a fortiori*, amorphous disulphide would give, under similar conditions, still more free sulphur because it is the most soluble of the three. The evidence for the existence of amorphous disulphide in the products of alkaline solutions is as follows: While the products of acid solutions which contain the most marcasite are the best crystallized, those from alkaline solutions which, judging by their oxidation coefficients, contain the most, are almost black, dull and lusterless at the lower temperatures. The quantity of pyrite is increased by raising the temperature or prolonging the time of reaction,—both conditions which are favorable to the crystallization of an amorphous substance. Moreover, *marcasite is not changed* by heating in alkali polysulphide solutions, as we found by heating some of the natural mineral in powdered form for several days at 300° with polysulphide of sodium. The oxidation coefficient remained 14·5. The influence of temperature on the formation of pyrite from ferrous salts and alkali polysulphides is shown in Table III. The influence of time is proved by the two following experiments: 3 g. $FeSO_4.7H_2O$, 2·5 g. Na_2S, and 0·75 g. sulphur, and 100^{cc} water, were heated 2 days at 100°. The product contained about 75 per cent pyrite.* A similar system heated for 7 days at the same temperature gave a product containing about 95 per cent pyrite. The results are calculated on the supposition that they contain marcasite; if they contain amorphous disulphide instead, the true percentage of pyrite should of course be higher, since a given quantity of amorphous disulphide would be equivalent to a greater quantity of the less soluble marcasite, but the order of the results would of course remain the same. The products obtained at 300° were yellower,

* There is an apparent discrepancy between this last result and the one quoted in Table III under the caption "100°." In the latter case the excess of polysulphide was much smaller.

denser, and in direct sunlight showed a decided metallic luster, while their oxidation coefficients approach those of pure pyrite. It may therefore be safely stated that the product of the union of ferrous sulphide and sulphur from an alkali polysulphide solution is at first amorphous disulphide of iron which gradually crystallizes to pyrite.*

The formation of iron disulphide by the action of sodium thiosulphate on ferrous salts.—In the endeavor to explain the formation of pyrite and marcasite in nature, the following hypothesis presented itself. Iron disulphide of either form may oxidize under surface conditions to ferrous thiosulphate by direct addition of oxygen; this is transported by circulating waters to some point where it is reduced again to its former condition. In a partial study of the oxidation of marcasite, no trace of thiosulphate was discovered. At the same time the effort to obtain the disulphide of iron by reduction of the thiosulphate was successful. When water solutions of ferrous sulphate and sodium thiosulphate are heated in sealed tubes, even to temperatures under 100°, the iron disulphide is precipitated with sulphur. By quantitative experiments which follow, the reaction is proved to be:

$$4Na_2S_2O_3 + FeSO_4 = FeS_2 + 3S + 4Na_2SO_4.$$

Exp. 1. 5 g. $FeSO_4.7H_2O$, 18 g. $Na_2S_2O_3.5H_2O$, and 25^{cc} water were heated in a sealed tube for 9 days at 90°. All but a trace of the iron was precipitated. The precipitate of $FeS_2 + S$ was washed in air-free water and dried in vacuo. The sulphur was extracted by carbon disulphide and the residue of FeS_2 was weighed.

	Found	Cal. from the above equation
$FeS_2 + S$	3·82	3·85
FeS_2	2·17	2·16

Exp. 2. 2 g. $FeSO_4.7H_2O$, 18 g. $Na_2S_2O_3.5H_2O$ and 35^{cc} water were sealed in CO_2 and heated for one day at about 150°. The precipitate was filtered and washed with air-free water. The solution was boiled in a current of carbon dioxide to remove a trace of hydrogen sulphide, and an aliquot part was titrated with standard iodine solution.

No. 1. 1/5 of the solution required 16·135 g. iodine solution. Cal. for the whole, 80·675 g. iodine solution.

No. 2. 2/5 of the solution required 32·332 g. iodine solution.

* In a recent paper (Zs. angewandte Chem., xxiv, 97, 1911), "Die Bildung von Eisen Bisulphide in Lösungen und die Enstehungen der natürlichen Pyritlagern," W. Feld states that whenever sulphur and ferrous sulphide are boiled in neutral or weakly acid solutions, pyrite forms.

Cal. for the whole, 80·830 g. iodine solution. The iodine solution contained ·005445 g. iodine per g.

80·675 and 80·830 g. iodine solution are respectively equivalent to 0·858 and 0·860 g. $Na_2S_2O_3.5H_2O$. Therefore 7·142 g. and 7·140 g. $Na_2S_2O_3.5H_2O$ were consumed in the reaction. The equation demands 7·137 g. for 5 g. $FeSO_4.7H_2O$.

	Found	Cal.
$FeS_2 + S$	1·547	1·556
FeS_2	0·872	0·863

Sodium thiosulphate when heated with water in sealed tubes forms hydrogen sulphide and sodium sulphate. $Na_2S_2O_3 + H_2O = H_2S + Na_2SO_4$. The reaction at 200° is quite incomplete, though no thiosulphate was obtained when a solution of sodium sulphate saturated with hydrogen sulphide was heated under the same conditions. When 1 g. $Na_2S_2O_3.5H_2O$ and 20^{cc} water were heated 4 days at 200°, the thiosulphate undecomposed, as determined by standard iodine solution, was 0·753 g. 0·247 g. decomposed is equivalent to 0·141 g. Na_2SO_4. The solution after titrating with iodine was precipitated with barium chloride. $BaSO_4$ found 0·223 g. equivalent to 0·136 Na_2SO_4.

At first it was thought that the reaction between ferrous sulphate and sodium thiosulphate was to be explained as follows: (1) $Na_2S_2O_3 + H_2O = Na_2SO_4 + H_2S$, (2) $FeSO_4 + 4H_2S = FeS_2 + 3S + 4H_2O$. Later it was found that from *ferrous chloride* the same mixture of sulphur and FeS_2 was precipitated. Of course, the reaction represented by equation (2) could not go on with ferrous chloride. Therefore, the following is probably the true explanation of the reaction.

$$(1.)\ FeSO_4 + Na_2S_2O_3 = Na_2SO_4 + FeS_2O_3$$
$$(2.)\ FeS_2O_3 + 3Na_2S_2O_3 = FeS_2 + 3S + 3Na_2SO_4$$

Form of FeS_2 obtained by heating ferrous salts with sodium thiosulphate.—Neither marcasite nor pyrite is obtained pure in this reaction. The product shows in crusts the color of pyrite, but it is poorly crystallized and may contain amorphous disulphide. A product prepared at 90°, tested by Stokes' method, behaved like a mixture of 70 per cent pyrite and 30 per cent marcasite. Another product formed at 300°* tested in the same way acted like a mixture of 72 per cent pyrite and 28 per cent marcasite. Though this reaction—the reduction of ferrous thiosulphate by sodium thiosulphate—doubtless has no significance as applied to geology, it is probable that the ferrous thiosulphate might be reduced by other reagents, and it is possible that ferrous thiosulphate may be formed in nature under some conditions, but of this we have no evidence.

* This was the maximum temperature. The reaction may have been complete before this temperature was reached.

The transformation of marcasite into pyrite.—More than fifty years ago, Wöhler* tried the experiment of heating both minerals for four hours at the temperature of boiling sulphur (about 445°) without observing any change in either of them. Our own results indicate that marcasite undoubtedly changes here, but very slowly. When marcasite was heated at 610° in hydrogen sulphide gas for 3 hours, it lost about 2·5 per cent sulphur and became strongly magnetic, owing, of course, to the formation of some pyrrhotite. A finely ground sample, after being thoroughly boiled out with hydrochloric acid, appeared decidedly yellower and less lustrous than marcasite.†

The comparison is best made by placing the sample to be tested alongside of a fragment of marcasite which has had all tarnish removed by recent boiling in hydrochloric acid (Stokes). A finely ground and purified sample of the heated marcasite gave the oxidation number 56 instead of 14 as previously. At 525°, a sample of marcasite heated 4½ hours in hydrogen sulphide gave the oxidation number 55·8. Under similar conditions at 450°, a sample of marcasite heated 4 hours gave the oxidation number 15·7, which corresponds to 5·5 per cent of pyrite. The sample was returned to the furnace and heated again 5 hours. This time the top layer in the crucible gave, after purification, the oxidation number 27, corresponding to 53 per cent pyrite, while a deeper layer in the same crucible gave 31, which indicates about 61 per cent of pyrite. At 450°, therefore, dry heating in H_2S changes marcasite to pyrite rather slowly—50 per cent–60 per cent in 9 hours. Heated to 410° for 4 hours, the oxidation number was 13·5, showing that no measurable change had occurred.

J. Königsberger and O. Reichenheim‡ found a marked decrease in the electrical resistance of marcasite in the neighborhood of 520°. They noted that the sulphide then possessed a specific resistance of the same order as pyrite, and rightly interpreted their results to mean that marcasite had changed into pyrite and the change is irreversible. It is difficult to see in their results, however, any support of their statement that the change appears to begin between 250° and 300°, while our results contradict it.

An effort was made to effect the transformation at a lower temperature in the wet way. At 350° marcasite heated in a sealed tube with a small amount of dilute sulphuric acid partly changed to ferrous sulphate and sulphur dioxide, but the solid

* Ann. Chem. Pharm., 90, 256, 1854.

† Pyrite is naturally a more lustrous mineral than marcasite. The duller color of heated marcasite is to be ascribed to the very large number of minute crystals in the product, and the lack of continuous surfaces.

‡ Neues Jahrb., ii, 36, 1906.

portion gave no sign of change, and at 300° a powdered sample which was repeatedly heated for several days' time with sodium sulphide and polysulphide solutions was equally unaffected.

Density.—The density of the marcasite heated to 610° rose from 4·887 to 4·911. The density of pure pyrite is 5·02+ The change in color, and, more convincingly, the oxidation number, show that the substance is pure pyrite after heating, yet its density is too low. The explanation is probably to be sought in the porosity of the product.

Influence of pressure on the change marcasite→pyrite.—Dr. A. Ludwig, at our request, kindly undertook some experiments on the influence of pressure in transforming marcasite to pyrite. A few grams of marcasite were compressed for five hours at a pressure of about 10,000 atmospheres. At the end of the period, the oxidation by Stokes' method showed no change in the substance. Later Johnston and Adams devised an apparatus in which the marcasite could be heated by a resistance coil while subjected to hydrostatic pressure of about 2000 atmospheres in petroleum oil. A number of experiments were tried between 300° and 400°, but Stokes' reaction showed no pyrite formation. The oxidation method was perhaps not quite so certain here on account of the fact that the oil was partially decomposed at the higher temperatures and the product may have contained some reducing matter which could not be removed by petroleum "ether." A mixture of pyrite and marcasite containing any such reducing impurity, as we have seen (p. 184), would give too low an oxidation number. Thus it might happen that a little pyrite could be overlooked. These experiments are of considerable interest because there are very few data on the effect of pressure in irreversible changes.* We do not know whether a difference in density in the right direction would favor the change or not, since Le Chatelier's law applies only to reversible changes. If the speed of the change is influenced by pressure quite apart from the volume relation, it may perhaps be retarded rather than accelerated. Until apparatus is developed which will give higher temperatures and at the same time high pressures, this problem must wait. At present the assumption,† which has been made in geology, that pressure favors all changes which are accompanied by reduction in volume, irrespective of their reversibility, is unwarranted.

Monotropic relation of marcasite to pyrite.—A crucible containing 50 g. pyrite was rapidly heated (20° per minute) in H_2S

* Van't Hoff, Vorlesungen, 2nd. Ed., Braunschweig, 1901, vol. I, p. 236.

† See Van Hise, A Treatise on Metamorphism, Monograph No. 47, U. S. Geol. Survey, 1904, pp. 215, 363.

over a range from 400° to 600°. The curve was perfectly smooth. When a similar charge of marcasite was heated in the same way, an acceleration of the temperature was plainly seen on the curve between 500° and 600°. (See fig. 5.) The

FIG. 5.

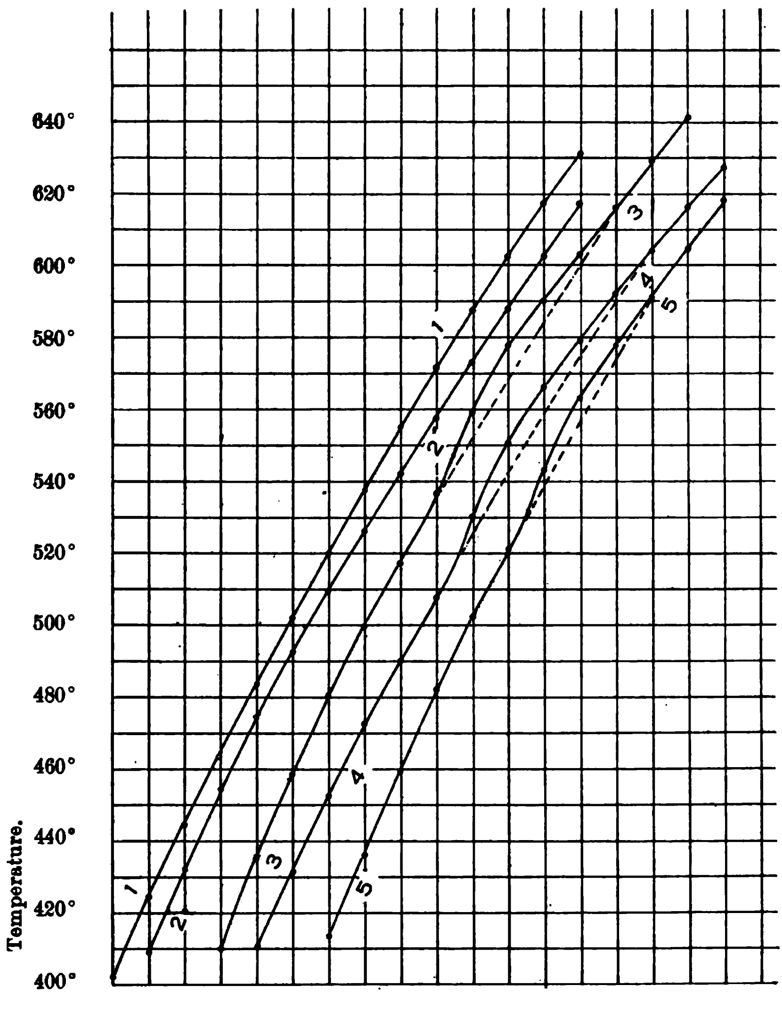

FIG. 5. Thermal curves showing evolution of heat when marcasite is changed into pyrite. (Curves 3, 4 and 5.) Curves 1 and 2 are thermal curves of pyrite.

experiment was repeated several times with similar results. Under these conditions, there is a plain evolution of heat accompanying the change of marcasite into pyrite. This shows, of course, that marcasite possesses the more energy* of the two and is a monotropic form. This condition of instability is in accord with the more rapid oxidation of marcasite in nature, and in it is probably to be found the reason for the difference in behavior between marcasite and pyrite toward other oxidizing agents. Monotropic forms often crystallize from some particular solvent or within a limited temperature range. The formation of marcasite from acid solutions is in accord with this, though as yet we do not understand the reason for it. A rise in temperature doubtless increases the velocity of the change marcasite → pyrite. At low temperatures this becomes infinitesimal or zero; above 450° it becomes measurable. This irreversible relation has a bearing on the question of paramorphs of iron disulphide, for it is impossible to see how pyrite could change to marcasite without first passing into solution, while the opposite change is experimentally established. Paramorphs of pyrite after marcasite are certainly possible, but paramorphs of marcasite after pyrite are evidently impossible.

The agency of organic matter in the formation of natural pyrite and marcasite.—The fact that pyrite is sometimes found in nature replacing wood has been alluded to. Liversidge† gives an example of recent pyrite which is found on twigs in a hot spring at Tampo, N. Z. The sulphides of southwestern Missouri, including pyrite and marcasite, are frequently associated with asphaltic matter, and in Oklahoma this is sometimes so great in quantity as to interfere with the concentration of the ores. (Lindgren.) It is pretty generally believed by geologists that the organic matter of certain shales acted as a precipitant of the pyrite they contain. Such a shale underlies the sulphide deposits of Wisconsin. We learn from Mr. W. H. Emmons of the U. S. Geological Survey that this shale contains a small quantity of hydrogen sulphide, which naturally may have been the precipitating agent. Coals, also, in which pyrite is commonly found, are frequently permeated with hydrogen sulphide.

The role of micro-organisms in the formation of iron disulphide.—The question naturally arises whether there is any connection between organic matter and the formation of

* Cavazzi (Rend. Accad., Bologna, N. S., ii, 205, 1898) states that the heats of combustion of pyrite and marcasite are identical (1550 cal.). This is certainly incorrect.

† J. Royal Soc. N. S. Wales, xi, 262, 1877.

hydrogen sulphide. In the putrefaction of organic matter hydrogen sulphide is one of the products, and Gautier* has surmised that the pyrite which sometimes forms the substance of fossil bones and shells is precipitated by hydrogen sulphide which is given off slowly by the organic matter during its decomposition. The formation of pyrite in this case would differ from that described in the previous pages only in the source of the hydrogen sulphide, which is here a product of micro-organisms.

There is another way in which micro-organisms produce hydrogen sulphide, and that is by the reduction of sulphates. According to Beyerinck,† a considerable number of bacteria, algæ, flagellata and infusoria show this kind of activity. Spirillum desulfuricans is one of the most important. As these organisms are active only in neutral or alkaline solutions, ferrous sulphide is precipitated whenever ferrous salts as well as sulphates are present. The black mud of many swamps, pools, and even seas (e.g., the Black Sea), as well as sea coasts,‡ which are intermittently overflowed, contains ferrous sulphide. Mr. C. A. Davis of the U. S. Bureau of Mines, who has had large experience on this subject, informs us that he has always found hydrogen sulphide in peat-bogs into which tide-water finds its way. Apparently, the formation of pyrite or marcasite through the agency of micro-organisms has not been observed, but only an influx of air with excess of hydrogen sulphide would be needed to change the ferrous sulphide into disulphide. That micro-organisms are directly responsible for any great quantity of the pyrite or marcasite of nature seems unlikely because in the first place they are probably not active far from the surface of the ground. They have been discovered at depths of only four or five meters.§ A fraction of a per cent of free acid usually inhibits the growth of these organisms; therefore they could not live in the solutions from which marcasite appears to have formed. Pyrite and marcasite are not infrequently associated with minerals like chalcopyrite, which proves the presence of copper in the original solutions, and copper is exceedingly poisonous to practically all micro-organisms. It is possible, however, that the reduction of sulphates like gypsum and sodium sulphate by micro-organisms may be an important source of hydrogen sulphide in nature.

Distinct conditions leading to pyrite or marcasite in nature.—The geological relations of marcasite indicate that it is a

* C. R., cxvi, 1494, 1893.

† Centr. Bakter. u. Parasitenkunde, i, pp. 1, 49, 104, 1895.

‡ H_2S was found in sea-water by B. Leroy, Ann. Ch. Ph., lviii, 332, 1846.

§ Hygiene des Bodens, Josef von Fodor, Jena, vol. i, Pt. I, p. 137, 1893.

product of surface conditions. The oxidation of either pyrite or marcasite gives first a mixture of sulphuric acid and ferrous sulphate which by further oxidation easily gives ferric sulphate. The action of hydrogen sulphide and atmospheric oxygen simultaneously on the acid ferrous solution would lead to the same goal. We have found how hydrogen sulphide acting on acid solutions, especially in the cold, gives rise to marcasite. We have also found that above 450° marcasite could not form, thus further confirming geological deductions.

Pyrite, being a stable form, probably crystallizes under a considerably wider range of conditions than marcasite. The evidence of synthetic study is that the formation of pyrite is favored by high temperature and by solutions which contain little or no free acid. In accord with these, we have the following geological deductions. First, pyrite is a product of hot springs. In the springs of Carlsbad, which have a temperature of about 55° C., recent pyrite is observed.* The waters contain sulphates and a trace of hydrogen sulphide, and are slightly alkaline. The lagoons of Tuscany are depositing pyrite from their hot waters. Bunsen† found that the hot vapors of the fumaroles of Iceland were gradually changing the ferrous silicate of the basalts into pyrite.

More important geologically is the fact that the product of deep veins by ascending waters is always pyrite, never marcasite. Such waters are naturally hot, and commonly if not always alkaline.‡ We can now see that a separation of pyrite from a magma is entirely possible, while the temperature of any magma would doubtless be incompatible with the existence of marcasite.

The occurrence of pyrite and marcasite together.—Hintze§ mentions thirty-one instances where pyrite and marcasite are found intergrown or precipitated one upon the other. Stokes‖ also tested a number of specimens which proved to be mixtures of pyrite and marcasite, some of them intergrown in concentric layers. In other places, e.g., in Joplin, Missouri, the two minerals have been observed by us in the same hand specimen.¶ According to F. L. Ransome,** the two minerals occur together, though perhaps not intergrown, in Goldfield, Nevada. These facts show very strikingly not only the small influence of nuclei in directing the form of the disulphide

* Daubrée, Géologie expérimentale, Paris, 1879, p. 93.

† Pogg. Ann., lxxxiii, 259, 1851.

‡ A hot acid solution in contact with carbonate or most silicate rocks would first be neutralized and then become alkaline.

§ Lehrbuch der Mineralogie, vol. i, pp. 724–778, 820–832.

‖ Loc. cit.

¶ See W. S. T. Smith and Siebenthal, U. S. G. S. Folio 148.

** Private communication. Specimens were also submitted by Mr. Ransome.

which separates from solution, but also that comparatively slight differences in conditions may give rise to one or the other. Further, that the two minerals may have formed at the same time in some instances. The synthetic experiments which have been described proved that the minerals very commonly formed together,* as polymorphic forms which are monotropic are apt to do. Cold solutions which were sufficiently acid gave marcasite; warm or hot solutions, either neutral or alkaline, gave pyrite, and intermediate conditions gave mixtures.

II. Pyrrhotite.

Composition.—Special interest attaches to the composition of pyrrhotite, which, despite much discussion, is still an unsettled question. The various formulae,† Fe_7S_8, $Fe_{11}S_{12}$, Fe_nS_{n+1} and FeS which have been assigned to it by various authors rest on widely varying analytical data. The analytical methods have no doubt been at fault, but the more important question concerns the physical homogeneity of the substance. This has been unusually troublesome. Pyrrhotite almost always occurs in the massive condition, a circumstance which naturally arouses suspicions of its purity, while its opacity makes it impossible to put the question to an optical test.

Many years ago Lindström‡ subjected all the known analyses of this mineral to a careful critique. Those which for any reason, such as defective analytical methods or impure material, appeared unconvincing were rejected.§ In the remainder, the ratio‖ of iron to sulphur was calculated and found to vary from 1:1·06 up to 1:1·19. Some years later Habermehl¶ investigated the same question. He crushed pyrrhotite to a fine powder, covered it with water, and endeavored, by means of a strong horseshoe magnet, to separate it into fractions varying in magnetic intensity. Such fractions as he obtained in this way showed no systematic difference in composition. Habermehl used in his experiments the pyrrhotite from Bodenmais.

A very satisfactory general discussion of the question of admixtures in pyrrhotite is also given in Habermehl's paper. He decided that pyrrhotite could not contain free sulphur because carbon disulphide removes none from it, neither could

* It may be, however, that pyrite was formed first and was succeeded by marcasite as the acidity of the solution increased.

† Sidot judged from experimental work with Fe_3O_4 and H_2S that pyrrhotite should have the formula Fe_3S_4, C. R. lxvi, 1257, 1868.

‡ Öfv. Ak. Stockh., xxxii, No. 2, 25, 1875.

§ 18 analyses out of 43 were thus rejected.

‖ In the calculation of the ratios Lindström took, in place of the small percentage of nickel found in many of these analyses, the equivalent of iron.

¶ Ber. Oberhess. Ges. für Natur- und Heilkunde, xviii, 83, Giessen, 1879.

it contain any disulphide of iron because this is insoluble in hydrochloric acid, while only sulphur remains after pyrrhotite has been boiled with this reagent. Judging from the properties ascribed to Fe_2S_3, he concluded that this also could not be present. Habermehl was thus forced to conclude, like Lindström, though on the basis of further evidence, that pyrrhotite was variable in composition, and it may here be said that no evidence of later date has ever disproved this conclusion. At that time a homogeneous solid of variable composition was an anomaly. To-day such substances are quite generally recognized under the category of solid solutions.

Hypothesis of solid solution.—We proposed to test the hypothesis of solid solution by preparing a series of synthetic pyrrhotites and measuring some property of them. Pyrrhotite was prepared by Berzelius, Rammelsberg and others, generally by heating pyrite. One can also begin with marcasite, which, as we have seen, is first changed to pyrite between 450° and 600°, or with sulphur and iron. We have tried all three methods, though most of the work has been done with pyrite from Elba. This very pure mineral, an analysis of which was given on p. 177, Part I, was kept in a vacuum desiccator, from which portions were taken from time to time as required.

Apparatus.—The apparatus used in the synthesis of pyrrhotite appears in fig. 6. The crucible, *C*, containing the pyrite is of unglazed porcelain, 48^{mm} high$\times 37^{mm}$ outside diameter at the top and 22^{mm} at the bottom. It has a doubly perforated graphite cover, *E*, through the central orifice of which passed the glazed Marquardt jacket, *A*, which shields the thermo-element. Through the second orifice passes a similar tube, *B*, open at the lower end, which is traversed by a current of hydrogen sulphide.*

The crucible is inclosed in a large porcelain tube, *D*, $40-45^{mm}$ inside and 50^{mm} outside diameter, and 50^{cm} in length. In some of the experiments the crucible was supported in the hot zone by a strong graphite rod, *G*, which was fastened to the cover, *E*, and clamped outside the large tube, *D*, while the cover itself was fastened to the crucible by three small pegs. By means of this device, the crucible could be quickly lowered at any time to the bottom of *D* and thus rapidly cooled. In other experiments, a much shorter porcelain tube was substituted for *D*, in which instances the crucible was supported by a fire-clay pedestal which rested on the bottom of the tube. The upper

* Since the ferrous sulphide from which hydrogen sulphide is generated, contains free iron, the gas was passed through boiling sulphur to remove hydrogen, before reaching the furnace.

FIG. 6.

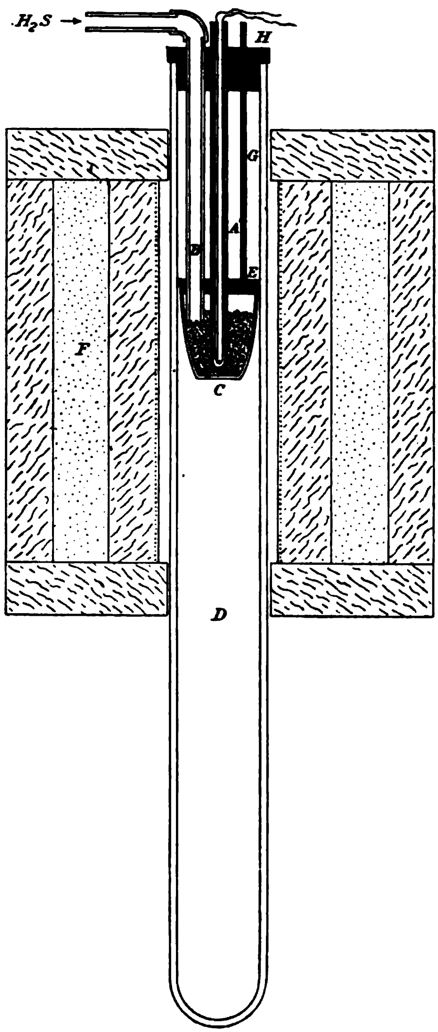

FIG. 6. Apparatus for the preparation of pyrrhotite.

end of the tube in all cases is closed by the graphite cover, *H*, through which pass *A* and *B*. The crucible and its contents are heated by a platinum-resistance furnace, *F*, as shown in the figure.

Synthesis.—When heated in hydrogen sulphide, pyrite decomposes gradually into sulphur and pyrrhotite. The decomposition may be first detected at about 575° (see p. 205). At about 665° it proceeds rapidly; still, even after some hours at 750°, the dissociation is never quite complete, and when the pyrite used is rather coarse (sized between screens of 8–40 meshes per cm.), several per cent of it persist in the product. The latter is therefore melted and cooled, and the resulting material, which is now free from pyrite,* serves as a starting point in the preparation of pure pyrrhotite.

When this is reheated it loses or gains sulphur according to conditions. A series of products was made by heating the sulphide in hydrogen sulphide for some hours at different measured temperatures, and then cooling it in nitrogen.† To facilitate the formation of homogeneous products the sulphide was carefully sized between screens of 16 and 40 meshes per cm. These products were all similar in appearance to natural pyrrhotite. They were all dense, opaque, metallic, more brownish than pyrite, and only very slightly tarnished. Some tests were made to prove that the quantity of oxide on the surface was negligible.

Weighed samples were heated in dry hydrogen to a red heat and the water formed was absorbed by passing through a calcium chloride tube. The surface of the grains became bright in a few minutes. The tube was cooled in hydrogen, which was then displaced from the apparatus by dry air. The water thus collected corresponded to less than 0·1 per cent of oxygen in two different tests. Furthermore it will be noted later that the preparations which were cooled in nitrogen were comparable in density with those which were prepared in another way and were not tarnished in the slightest degree (see p. 199).

Composition of synthetic pyrrhotite.—The sulphur was determined in each of the synthetic pyrrhotites by a method‡ worked out in this laboratory, which was proved accurate within at least 0·2 per cent of the sulphur present.

Treitschke and Tammann§ state that the fused sulphide of

* Except for a slight superficial layer which decomposes in the next process.

† The nitrogen was prepared by Knorre's method (Die Chem. Ind., xxv., 531, 550, 1902; Chem. Centralb., i, 125, 1903), i. e., by dropping a saturated solution of sodium nitrite from a dropping funnel into a solution of ammonium sulphate and potassium chromate. The gas was passed through dilute sulphuric acid to remove ammonia, and then successively through long columns of chromic acid to remove oxides of nitrogen; sulphuric acid to remove moisture, and finally over-heated copper to remove oxygen, or any traces of oxide of nitrogen which may have escaped.

‡ Allen and Johnston, Jour. Ind. & Eng. Chem., ii, 196, 1910; Zs. anorg. Chem., lxix, 102, 1911.

§ Z. anorg. Chem., xlix, 320, 1906.

iron corrodes and dissolves porcelain, but it should be noted that they made their fusions in carbon-resistance furnaces without further protection from the air.

Our unglazed crucibles appeared quite unattacked in an atmosphere of hydrogen sulphide. Analyses revealed the presence of about 0·25 per cent of silica in our preparations, though we believe that most of this was derived from minute fragments of the crucible, which are difficult to exclude entirely when the cake of sulphide is broken out of the crucible. Thus No. 7 gave 0·33 per cent, No. 10, 0·26 per cent, and No. 3 gave 0·22 per cent and 0·24 per cent of silica in duplicate determinations. This of course includes the silica in the original pyrite, which, however, was negligible, —·04 per cent.

Relation of the specific volume to the composition.—The specific gravity* of each preparation was determined and from

TABLE IV.†

Composition, density and specific volumes of pyrrhotites.

	Total Sulphur	Cal. FeS	Cal. dissolved S.	Sp. gr. at 25°	Cal. dens. at 4°	Cal. Sp. V.
1	36·72	99·59	·41	4·769	4·755	0·2103
2	36·86	99·37	·63	4·768	4·755	0·2103
3	37·71	98·04	1·96	4·691	4·677	0·2138
4	38·45	96·89	3·11	4·657	4·643	0·2154
5	38·54	96·73	3·27	4·646	4·632	0·2159
6	38·64	96·57	3·43	4·648	4·634	0·2158
7	38·84	96·26	3·74	4·633	4·619	0·2165
8	39·09	95·86	4·14	4·602	4·589	0·2179
9	39·49	95·23	4·77	4·598	4·585	0·2181
10	40·30	93·96	6·04	4·533	4·520	0·2212

† *Conditions of formation.*

1. From pyrite, melted in H_2S, kept a little above m. p. for 1 h. in nitrogen and then cooled in nitrogen.
2. From sulphur and iron, otherwise like 1.
3. From pyrite, heated to equilibrium in H_2S at 1300°, then quickly cooled.
4. From pyrite, heated in H_2S to 900°, then cooled in nitrogen.
5. From pyrite, melted in H_2S and cooled rather slowly in same.
6. From marcasite, melted in H_2S and cooled rather slowly in the same.
7. From pyrite, heated to 800° 6 h. in H_2S, then cooled in nitrogen.
8. From pyrite, heated to 700° 2¼ h. in H_2S, then cooled in nitrogen.
9. From pyrite, heated to 600° 3 h. in H_2S, then cooled in nitrogen.
10. From pyrite, heated to 600° 15 h. in H_2S, then quickly cooled in the same.

* Day and Allen, Publication No. 31, p. 55, Carnegie Institution of Washington.

this the density (at 4°) and the specific volume was calculated. Table IV contains these data. Column 1 contains the total percentage of sulphur, Columns 2 and 3 the quantities of FeS and S calculated on the hypothesis that pyrrhotite is a solid solution of sulphur in ferrous sulphide. In fig. 7 are plotted as abscissas the quantities of dissolved sulphur (Column

FIG. 7.

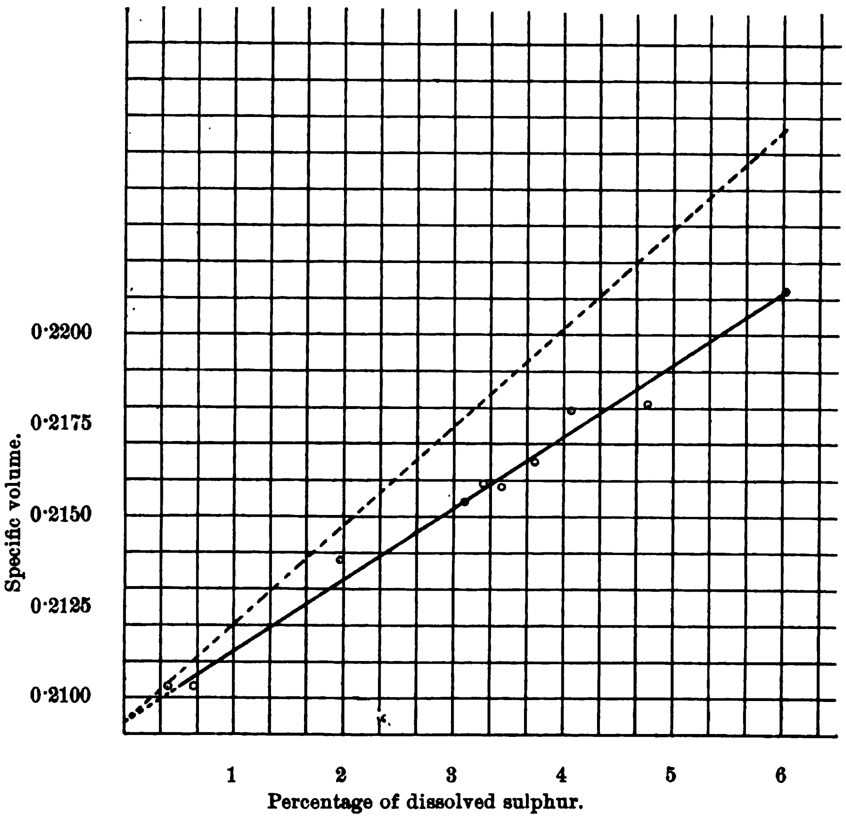

FIG. 7. The variation of specific volume with the dissolved sulphur in pyrrhotite.

3, Table IV), and as ordinates the specific volumes (Column 6, Table IV). It will be noticed that the scale of the plot is very large and the locus of the points is not only a continuous curve as the theory of solid solutions demands, but it is also a straight

line within the limits of the errors.* If we compare this line with the dotted line joining the specific volumes of sulphur and ferrous sulphide, we see that a considerable contraction has taken place in the process of solution.†

Equilibrium between solid pyrrhotite and the partial pressure of sulphur in hydrogen sulphide.—The composition of a variable phase of two components, iron and sulphur, as pyrrhotite is shown to be, would of course be fixed when both temperature and pressure are fixed. By heating in hydrogen sulphide the pressure is fixed, though not independently of the temperature. To obtain equilibrium, the products were heated for about three hours, at the measured temperature, and then by the device shown in fig. 6, the crucible and its contents were quickly lowered to the bottom of the enclosing tube. The process of heating and quick cooling in hydrogen sulphide was repeated until the density of the product was constant. The densities of the products thus successively prepared usually agreed exactly in the third decimal place. The rate at which the sulphur is absorbed by pyrrhotite in the cooling is too slow to affect these results except possibly in the determinations made at the highest temperatures (1100°–1300°), where a small quantity of sulphur may perhaps be taken up. As this point is important, some data on the rate at which the cooling proceeded are here given.

Initial temperature	1300°	1100°	800°	600°
Temperature after 1 min.	----	680°	----	----
" " 2 "	580°	480°	----	----
" " 3 "	----	----	420°	----
" " 3½ "	----	400°	----	----
" " 5 "	----	----	----	305°
" " 6 "	365°	----	----	----
" " 10 "	----	165°	----	----

In Table V are collected the quantities of sulphur dissolved in pyrrhotite at different temperatures in hydrogen sulphide gas. The sulphur in Nos. 1 and 6 was determined by analysis; in the rest it was calculated from the specific gravity. The results in Table VI, showing the dependence of composition on temperature when the products are cooled in nitrogen, are given by way of control. In fig. 8, the curve in space shows how the composition of pyrrhotite varies with both tempera-

* Three of the points are beyond the errors of the determination of sulphur, and specific gravity, but if we allow a small error in homogeneity in the process of preparation, probably occasioned by the splinters of porcelain, the statement holds for these points also.

† The density of rhombic sulphur is very nearly 2·075, and its specific volume is therefore 0·4819. The specific volume of the ferrous sulphide is estimated by extrapolation to be 0·2093.

ture and pressure. The discontinuity in the curve between 1165° and 1200° which is conditioned by the change of state will be discussed later (p. 207).

Maximum percentage of sulphur in pyrrhotite.—The most concentrated solution of sulphur in ferrous sulphide obtained

Fig. 8.

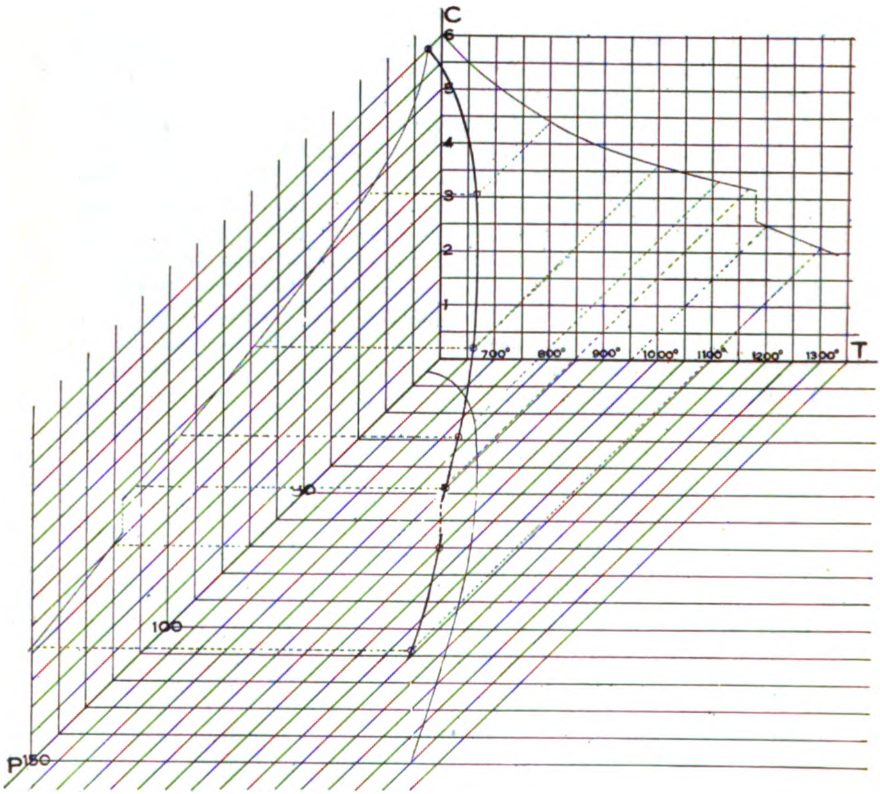

Fig. 8. Curve in space showing the dependence of the composition of pyrrhotite on temperature and pressure.
C (composition) = percentage of dissolved sulphur.
P = pressure in millimeters of mercury.
T = temperature.

synthetically contains 6 per cent of sulphur and 94 per cent of FeS. This solution was obtained at 600°, where the absorption of sulphur from hydrogen sulphide is slow. At 575° the reaction was so slow that the attempt to get a saturated product was discontinued. At 550°, as we will show farther on, pyrite is formed. The curve in fig. 9 shows an extrapola-

TABLE V.

Sulphur dissolved by FeS in an atmosphere of H_2S at measured temperatures.

	Temperature	Time of heating		Percentage of dissolved sulphur
		Time in which equilibrium was reached	Total	
1	600°	12 h.	15 h.	6·04
2	800°	3 "	7 "	4·41
3	1000°	2 "	4 "	3·6
4	1100°	2 "	4 "	3·3
5	1165°	1 "	2 "	3·2
6	1200°	20 min.	1½ "	2·5
7	1300°	20 "	1 "	1·96

TABLE VI.

Sulphur in pyrrhotite cooled in nitrogen from various temperatures.

	Temperature	Time of heating in H_2S	Percentage of dissolved sulphur
1	1210°	Few minutes	·41
2	About 1200°	1½ h.	·63
3	1000°	6 h.	2·70*
4	900°	6 h.	3·11
5	800°	6 h.	3·74
6	700°	2½ h.	4·14
7	600°	3 h.	4·77

* The sulphur in No. 3 was calculated from the density.

tion from which we judge the maximum quantity of sulphur in pyrrhotite obtained by heating in hydrogen sulphide must be about 6·5 per cent. If we compute the analyses of natural pyrrhotite in terms of FeS and S, we find that the limit of solubility agrees well with this. The highest value calculated from Lindstrom's† figures is 6·08 per cent. From Rose's‡ analyses we derive the value of 6·76 per cent. The maximum percentage of sulphur in the pyrrhotite analyses quoted by Dana§ is 40·46 per cent. This particular occurrence, however, contained about 0·5 per cent of copper and cannot, therefore, be satisfactorily

† Loc. cit.
‡ Gmelin Kraut Handbuch der Ch., 6th Ed., Vol. III, pt. 1, 332.
§ System of Mineralogy, 6th Ed., p. 74.

used for a calculation of this sort. Dana gives also an analysis of pyrrhotite by Funaro, which contained 40·27 per cent total sulphur, equivalent to 6 per cent of dissolved sulphur. This pyrrhotite contained also 3·16 per cent of nickel, which, according to Penfield, is mechanically intermixed with pyrrhotite in the form of pentlandite. If this be true, the ratio of sulphur to

FIG. 9.

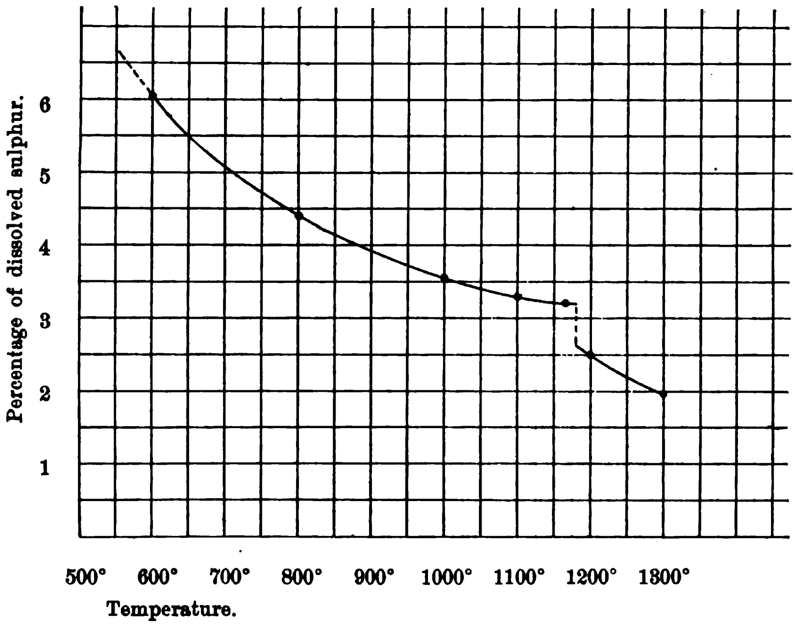

FIG. 9. Curve showing the percentage of sulphur dissolved by ferrous sulphide in hydrogen sulphide gas as the temperature varies.

iron in the pyrrhotite would be raised a little, since pentlandite belongs to the type of sulphides MS, and the equivalent quantities of iron and nickel are almost the same.

Some allowance for errors in the analyses of the natural mineral should be made; still, the agreement between the maximum quantities of sulphur in the natural and synthetic pyrrhotite is striking.

Relation between pyrrhotite and pyrite.—The diagram in fig. 10 shows the relation between pyrrhotite and pyrite. The curve 1, 1 shows the partial pressures of sulphur vapor in one atmosphere of hydrogen sulphide, as they vary with temperature. These results are taken from Preunner and Schupp,* and

* Zs. phys. Chem., lxviii, 161, 1909.

are extrapolated above 1130° and below 750°. Curve 2, 2, represents so far as may be with partial data the dissociation pressures of pyrite at various temperatures. Here it is assumed that the vapor pressure at 665° is one atmosphere (see p. 205). At 550° pyrrhotite was found to pass over into pyrite when

FIG. 10.

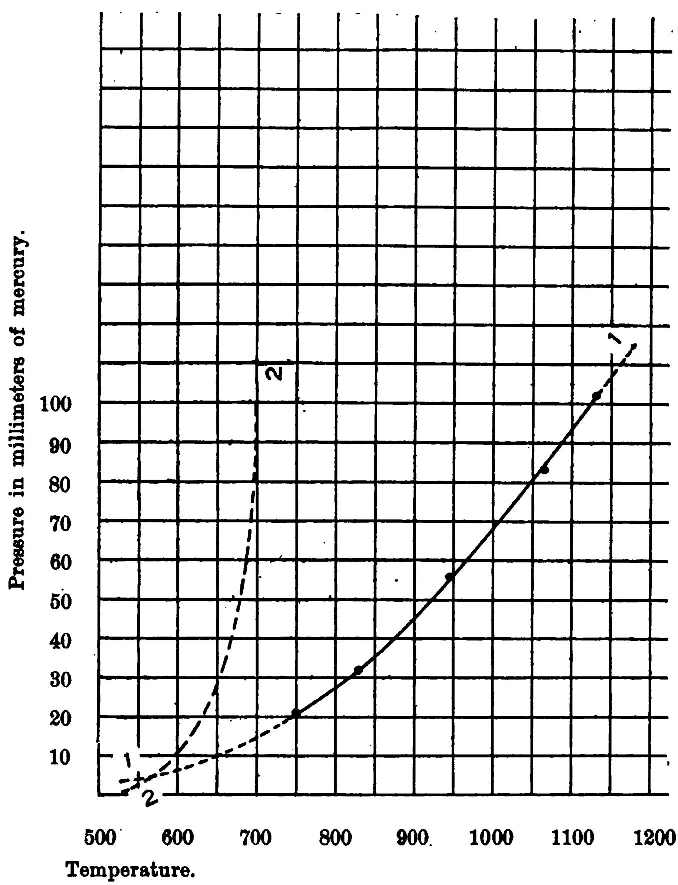

FIG. 10. Curve 1, 1, shows the partial pressures of sulphur in hydrogen sulphide at various temperatures (Preunner and Schupp). Curve 2, 2, shows approximately the dissociation pressure of pyrite.

heated in hydrogen sulphide. This was proved by the fact that the color changed to the yellower color of pyrite and the density increased, whereas pyrrhotite decreases in density with increase of sulphur. At 575° pyrrhotite showed no change in

Fig. 11.

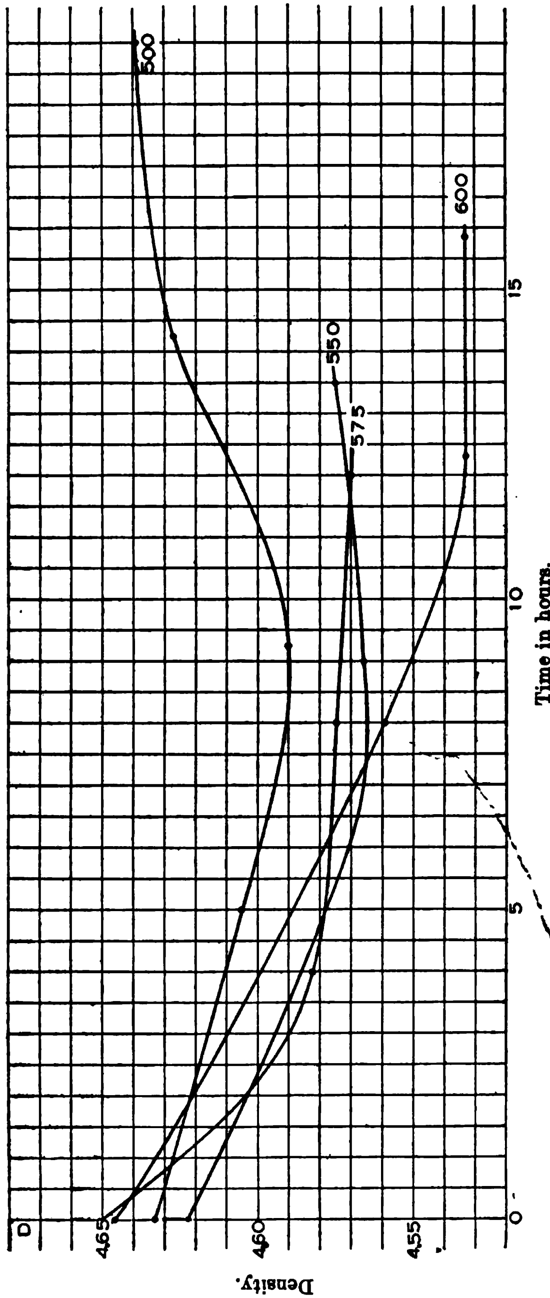

Fig. 11. Curves showing the change in specific gravity with time on heating pyrrhotite in hydrogen sulphide. The curves refer to the temperatures 500°, 550°, 575° and 600°.

color but continued to decrease in weight the longer it was heated. These facts are graphically shown in fig. 11. Pyrite under the same conditions gave inside of a few hours a perceptible quantity of pyrrhotite, which was proved by testing with warm hydrochloric acid. At 565° the pyrite formed in several hours only a doubtful trace of pyrrhotite, if any. Between 550° and 575°, therefore, the two curves 1, 1 and 2, 2 cross, and, at that point, about 565°, at a pressure of about 5^{mm} of sulphur, pyrite should be in equilibrium with a pyrrhotite containing about 6·5 per cent of dissolved sulphur. How this quantity would vary with conditions we do not yet know, though, as we have just seen, the solution of sulphur in ferrous sulphide of maximum concentration found in nature, formed presumably from water solutions, does not vary much from it.

The change from pyrite to pyrrhotite is, then, a reversible reaction, $FeS_2 \rightleftarrows FeS(S)_x + (1-x)S$. Since the system contains a gaseous phase, the temperature at which the change occurs is manifestly dependent on pressure.

Dissociation point.—It has been previously stated that pyrite undergoes dissociation into pyrrhotite and sulphur and that this dissociation is detectable at 575° after the lapse of several hours, when the heating is done in hydrogen sulphide. If the heating is continued at a moderate rate (2° per min.) a strong absorption of heat manifests itself at about 665°. Here, under these conditions of heating, the dissociation therefore becomes suddenly accelerated, and it is probable that the pressure of the escaping sulphur reaches one atmosphere. The solid phases pyrite and pyrrhotite, i. e., the saturated solution of sulphur in ferrous sulphide, should at a fixed temperature maintain a fixed pressure. As a matter of fact, the point is not sharp; the temperature gradually rises through an interval of about 20°. This is probably due to the formation of a coating of pyrrhotite on the pyrite grains, which retards the dissociation, so that the system requires a gradually rising temperature to maintain the pressure. The fact that undecomposed pyrite persists so tenaciously in the product seems to support this view. A typical thermal curve for pyrite in this region is shown in fig. 12. It is seen to have the same general form as a melting point curve and the end of the heat absorption is more sharply marked than the beginning, though for the reasons stated the latter has the greater significance. The following data show that the absorption ends pretty uniformly at about 685°:

El. V	6050 mv.	= 686°
"	6037 mv.	= 684°
El. S	6083 mv.	= 686°
"	6060 mv.	= 684°

Inversion in ferrous sulphide.—Le Chatelier and Ziegler* discovered a transformation in commercial ferrous sulphide at about 130°. This has been confirmed by Treitschke and Tammann† and by Rinne and Boeke.‡ The last named

FIG. 12.

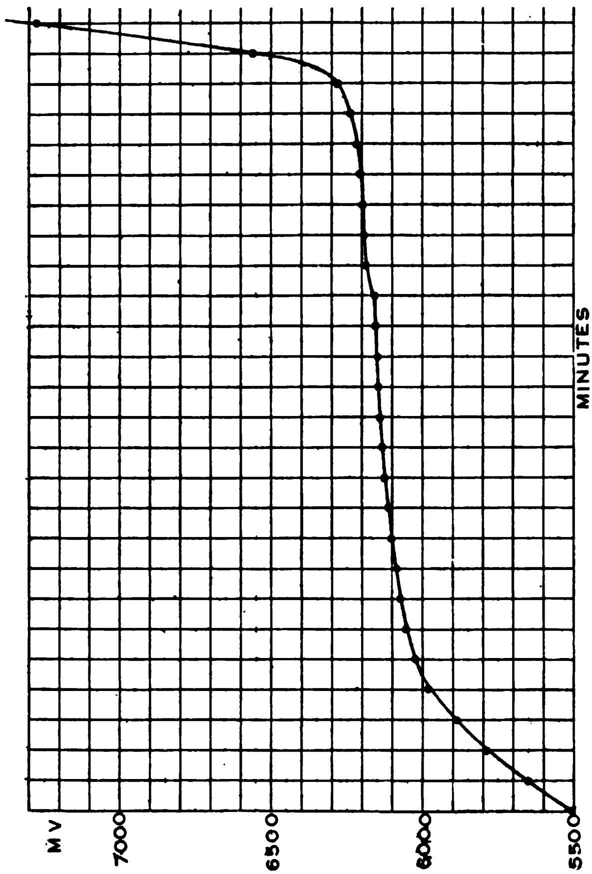

FIG. 12. Curve showing the dissociation of pyrite into pyrrhotite and sulphur.

authors were unable to find any heat absorption in approximately pure ferrous sulphide, though the addition of iron (or carbon), which they believe goes into solid solution, makes the heat change manifest. The dissolved iron is supposed by

* Bull. Soc. d'Encouragement de l'Industrie, Sept. 1902, 368.
† Loc. cit.
‡ Zs. anorg. Chem., liii, 338, 1907.

Rinne and Boeke to facilitate the transformation, first by raising the temperature at which it takes place, and second by loosening the crystal structure. The transformation point in the presence of 7 per cent dissolved iron is found to be 138°, and further addition of iron does not change it. At lower temperatures a temperature interval is found, and the inversion is lowered, but the temperature cannot be followed in mixtures containing less than 5 per cent dissolved iron. Our results confirm the above in so far as the experiments were carried. The change could not be detected in pyrrhotite or pure troilite. It is a natural inference that the change *does take place in these also*, but that presumably the heat absorption in them is very gradual and is therefore overlooked.

Melting temperature of pyrrhotite.—Pyrrhotite melts in hydrogen sulphide at 1183°. (Table VII.) Of course, a solid solution melts through an interval and not at a point, but we have as yet no quantitative methods which enable us to determine the length of such an interval at high temperatures. The maximum of the heat absorption falls at the above point. The melts seem to be quite thin,* and there is usually little or no undercooling, if the temperature is not too rapidly lowered.

TABLE VII.

Preparation	Thermoelement	Melting temperatures		Freezing temperatures	
		mv.	degrees	mv.	degrees
1	V	11589	1181	11590	1181
2	"	11585	1181		
3	"			11585	1181
4	A	11683	1183		
5	"	11687	1183		
6	"	11675	1182		
6	"	11700	1184		
7	"	11705	1184		
8				11690	1183

Examples of freezing and cooling curves of pyrrhotite in hydrogen sulphide are plotted in fig. 13. By reference to fig. 9 we notice that the liquid pyrrhotite contains still a considerable excess of sulphur above the ferrous sulphide ratio, and that the quantity is less than it is in the solid. From Beckmann's formula† for the change of melting temperature with

* See Friedrich, Metallurgie, vii, 257, 1910.
† Ostwald's Lehrbuch der Chemie, vol. ii, pt. 3, p. 38.

composition in a solid solution $\Delta = \frac{\cdot 02\ T^2}{l}(C_1 - C_2)$, where Δ is the change in the melting point, T is the melting point (absolute) of the solvent, l is the heat of fusion of the same, and C_1 and C_2 the concentrations of the solute in the liquid and solid respectively, we find that the melting temperature is raised if

Fig. 13.

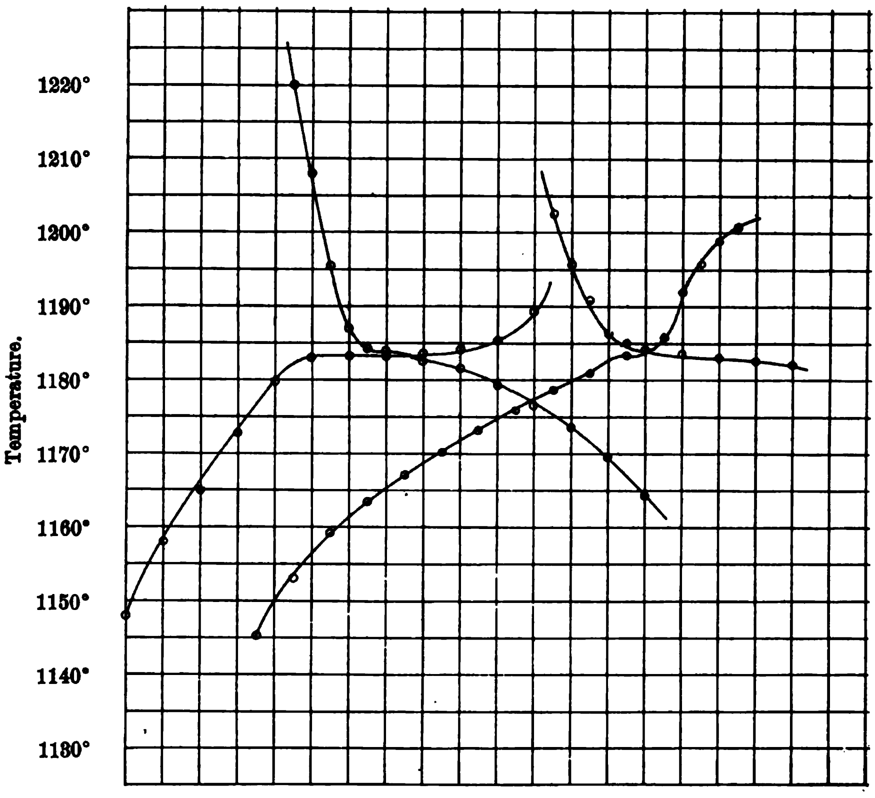

Fig. 13. Melting and freezing curves of pyrrhotite in hydrogen sulphide.

the *liquid which first forms* contains less of the solute than the original solution. We do not, to be sure, know the composition of the *first* liquid which forms, but as the *final* liquid product contains less sulphur than the original solid, it is impossible to believe that this is not the case with the first liquid also.

Melting temperature of pyrrhotite in sulphur vapor.—If this conclusion is correct, it follows that by raising the pressure

of the sulphur vapor in which the pyrrhotite is melted, the quantity of sulphur in the product should also be raised, and the melting point with it. In accord with expectation, the maximum heat absorption in melting was raised about 5° when the change of state took place in an atmosphere of sulphur vapor. The apparatus used was the same as that shown in fig. 6, except that a second furnace below the one shown in the figure was used for boiling the sulphur. At the bottom of the tube were placed 100 grams of sulphur, and the temperature of the lower furnace (measured outside the tube) was raised gradually to a little above the boiling point of the sulphur, and only after the sulphur burned freely at the top of the tube was the temperature of the crucible raised through the melting interval. The experimental data follow:

El. A	11740 m. v.	1188°
	11726 "	1187°
	11720 "	1186°

The maximum heat absorption is only about 5° higher than it is when the pyrrhotite melts in hydrogen sulphide. A careful comparison with the latter on a succeeding day in the same apparatus left no doubt as to the reality of rise in the temperature and as to its order of magnitude.

Melting temp. of pyrrhotite in H_2S on the succeeding day, with the same element and otherwise same conditions	11683 m. v.	1183°
	11686 m. v.	1183°

Melting point of ferrous sulphide, FeS.—Since the melting temperature of pyrrhotite is raised by increasing the pressure of sulphur vapor above it, pure ferrous sulphide must melt at a temperature lower than any of the sulphur solutions. In the effort to obtain this point the crucible containing the pyrrhotite was heated in a vacuum furnace. The dissolved sulphur volatilized in vacuo, as expected, but there was a further loss, though a slow one, which was found to be due to a dissociation of the ferrous sulphide into the elements, a circumstance which naturally prevented the exact location of the melting point.

The apparatus employed is shown in fig. 14. *A* is a glazed porcelain tube, closed at one end, 50^{cm} in length. The open end is closed by the perforated brass plug *D*, through which passes the porcelain tube *B* which protects the thermoelement *E* from the action of the fused sulphide. This plug has a side tube also of brass which connects with the pump. An airtight joint between the tube and plug is made with Kotinski cement, *CC*. It was found necessary also to close the tube *B* by

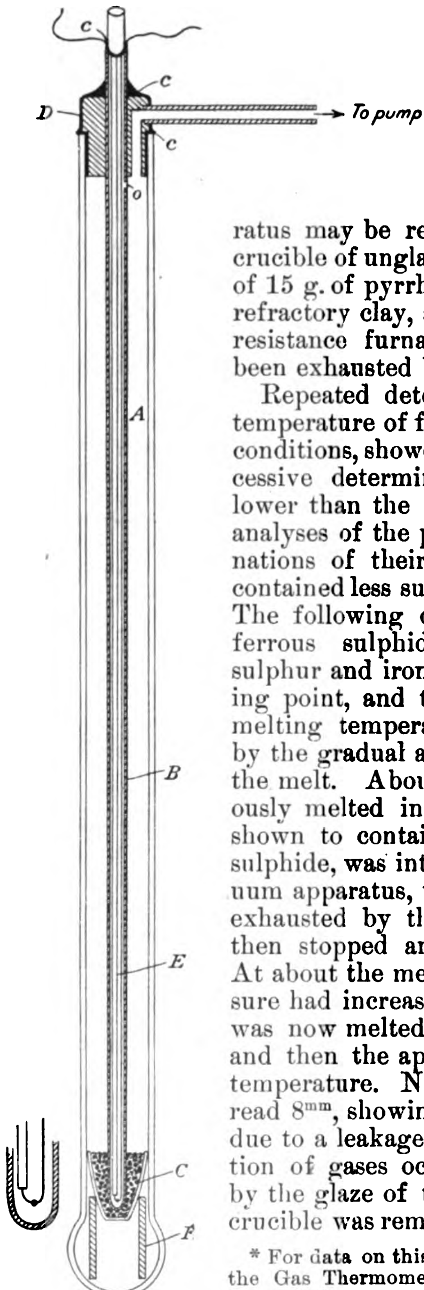

Fig. 14. Vacuum furnace.

cementing in a small glass plug, because the former invariably leaked through the closed end. A small hole is drilled through this tube at *O*, so that all the air in the apparatus may be removed by the pump. The crucible of unglazed porcelain has a capacity of 15 g. of pyrrhotite. It rests on a ring of refractory clay, and is heated as usual by a resistance furnace after the apparatus has been exhausted by the oil pump.

Repeated determinations of the melting temperature of ferrous sulphide under these conditions, showed in general that each successive determination was a few degrees lower than the one which preceded it, and analyses of the products as well as determinations of their density showed that they contained less sulphur than ferrous sulphide. The following data make it evident that ferrous sulphide slowly dissociates into sulphur and iron, in the vicinity of its melting point, and that the successively lower melting temperatures obtained are caused by the gradual accumulation of free iron in the melt. About 15 g. of a sulphide previously melted in the vacuum furnace, and shown to contain less sulphur than ferrous sulphide, was introduced again into the vacuum apparatus, which was then completely exhausted by the pump. The pump was then stopped and the heating was begun. At about the melting temperature the pressure had increased to $9{\cdot}5^{mm}$. The product was now melted and frozen several times, and then the apparatus was cooled to room temperature. Next morning the manometer read 8^{mm}, showing that the pressure was not due to a leakage but doubtless to the evolution of gases occluded by the crucible and by the glaze of the porcelain.* When the crucible was removed from the vacuum tube

* For data on this point, see Holborn and Day, On the Gas Thermometer at High Temperatures, this Journal (4), viii, 178, 185, 1899; Guichard, The Gases Disengaged from the Walls of Tubes of Glass, Porcelain, and Silica, C. R., clii, 876, 1911.

the contents were found to possess a bright metallic luster, while about 10^{cm} above the cover of the resistance furnace a ring of sulphur was condensed on the inside of the tube. This experiment was repeated with similar results. A sulphide containing 36·02 per cent of sulphur (FeS contains 36·45 per cent) was heated as before. This time the manometer read 5·5^{mm} at the melting temperature. When the apparatus was cold the reading was 5·0^{mm}. This product was also perfectly bright and a ring of sulphur was again visible* on the cool part of the tube. The product was analyzed again and found to have lost still more sulphur. The following table (Table VIII) shows that the percentage of sulphur, the specific gravity, and the last melting point of three different products prepared in vacuo are in accord, i. e., the density increases with the percentage of free iron and the melting "point" falls. The melting temperature of No. 3 should of course be lower than No. 2, but these temperatures are not easy to locate exactly; a part of the difficulty is perhaps due to the fact that we are dealing with a mixture, in which the heat absorption is not sharp.

TABLE VIII.

Properties of pyrrhotite after melting in vacuo.

No.	Melting temperature in microvolts	Melting temperature in degrees	Sp. gr. at 25°	Density (4°)	Sp. vol.	Per cent sulphur	Free iron calculated
1	11508	1165	4·816	4·802	·2082	36·02	1·23%
2	11346	1156	4·861	4·847	·2063	35·71	2·08
3	11416	1157	4·883	4·869	·2054	35·41	2·91

It is quite evident from the above data that the true melting point of ferrous sulphide can only be determined by heating in sulphur vapor, the pressure of which is equal to the dissociation pressure of the sulphide. We may safely say that this point will be found to lie between 1183°, the melting temperature of a product formed in hydrogen sulphide of one atmosphere pressure, and 1165°, and that the point is within 5° of 1170°. Treitschke and Tammann,† working with impure material, by extrapolation estimated the melting point of ferrous sulphide at 1300°. Biltz,‡ heating precipitated sulphide of

* The sulphur was identified by solution and crystallization from carbon bisulphide. About 100^{mg} was thus recovered.

† Zs. anorg. Chem., xlix, 328, 1906.

‡ Zs. anorg. Chem., lix, 273, 1908.

iron in an atmosphere of nitrogen, obtained 1197°±2°. Friedrich, who took considerable pains with the composition of his material, preparing it by the fusion of synthetic pyrrhotite with the calculated quantity of iron, found an average of 1171°.*

Crystals of pyrrhotite.—Measurable crystals of pyrrhotite were readily formed by the action of hydrogen sulphide on solutions of ferrous salts in glass tubes which contained some air. The yield was small and it cannot be stated, in the absence of optical tests, that the different crystals were identical in composition; in fact, Mr. Larsen finds crystallographic evidence that there were differences of composition. The manifest impossibility of finding the composition of individual crystals and of proving that the crystals of any one preparation were identical, made it useless to attack the interesting question, how the angles in crystals of the pyrrhotite series vary with composition. Crystals were prepared at 80°, at 225°, and at some other temperatures, therefore presumably above and below the inversion temperatures, but in the absence of direct evidence on either pure ferrous sulphide, or pyrrhotite of any composition (see p. 206) this can not be stated with certainty. Mr. Larsen believes there is good crystallographic evidence for two crystal forms, the upper form orthorhombic, the lower hexagonal.

Troilite and its relation to pyrrhotite.—The knowledge of troilite is defective on account of the scarcity and poor development of material, but the analyses on record, and its behavior towards acids, prove that it is essentially ferrous sulphide, contaminated generally with the sulphides of cobalt and nickel. The mineral is found only in meteorites embedded in a matrix of metallic iron, and it is evidently the contact with free iron and not the peculiar conditions of meteorite formation which accounts for the lack of dissolved sulphur in troilite. It is probable that the stony portions of meteorites contain ordinary pyrrhotite.†

Lorenz‡ has described a method for the preparation of ferrous sulphide (artificial troilite) which depends on the same principle, i. e., formation in the presence of excess of iron. Metallic iron is simply heated to redness in hydrogen sulphide. Crystalline crusts of silvery luster which are easily detached from the unchanged metal, are produced in this way. Analyses of these crusts by Lorenz approached ferrous sulphide, but not closely. The only determination of sulphur gave 37 per cent, which corresponds to 0·85 per cent of dissolved sulphur. Two products were made by us in this way. They agreed with Lor-

* Loc. cit.
† Dana, A System of Min., 6th Ed., p. 73.
‡ Ber., xxiv, 1501, 1891.

enz's description completely, but they were not ferrous sulphide. The first, formed at 850° from soft iron wire, had a specific gravity at 25° of 4·739, corresponding to a specific volume (4°) of 0·2116. The second, formed at 950°, had a sp. gr. of 4·748, corresponding to a specific volume of 0·2112. Making no allowance for the impurities in the iron, we calculate from these numbers (see p. 198) 1·1 per cent and 0·9 per cent of dissolved sulphur respectively. The diffusion of sulphur into the iron is evidently too slow here to give a homogeneous product. An examination of these crystals under the microscope, for which the authors are indebted to Dr. F. E. Wright, showed that they were either hexagonal or pseudohexagonal, but they were not adapted to measurement on the goniometer.

Efforts to prepare ferrous sulphide in the wet way were no more successful. Weinschenk* claims to have formed it by the action of hydrogen sulphide on a solution of ferrous chloride in sealed tubes. The product consisted of microscopic hexagonal plates, which Weinschenk states did not lose sulphur when heated to redness in hydrogen and therefore were ferrous sulphide. His experimental work is doubtless in error, for Habermehl,† many years earlier, had shown that pyrrhotite under these conditions loses sulphur continuously and gradually approaches pure iron.

Weinschenk's work was repeated by us. Pure ferrous chloride was prepared repeatedly with much care, dissolved in an aqueous solution of carbon dioxide and subjected to the action of hydrogen sulphide, made in several ways (by the action of the water on sodium thiosulphate; and by the action of dilute sulphuric acid on ammonium thiocyanate). In no case was pure ferrous sulphide obtained. Free sulphur, either from secondary reactions or perhaps from the dissociation of hydrogen sulphide, even at 200°, always appeared to give pyrrhotite. After our further experience in heating pyrrhotite in vacuo, we state with confidence that pure ferrous sulphide has doubtless never been made.

Mineralogically, troilite has no claim to a separate mineral species any more than have pyrrhotites of different composition; it is simply the end member of the series of solid solutions. This is abundantly attested by the synthetic evidence submitted in the foregoing pages. It may also be noted by way of further evidence that the specific gravity of natural troilite or rather the specific volume calculated from it, agrees tolerably well with the extrapolated value in fig. 7, and the best crystallographic‡ work on troilite, imperfect though the material was, indicates that it is hexagonal, as it should be.

* Zs. Kryst., xvii, 499, 1890. † Loc. cit.
‡ Linck, Ber., xxxii, 895, 1899.

Application of data on pyrrhotite to geology.—Very little of the chemistry of pyrrhotite worked out in these pages will probably find application in geology. However, the following points have a practical bearing.

1. The readiness with which pyrrhotite changes to pyrite, and the reverse, has been specially noted. The transformation of pyrrhotite into pyrite through the agency of vein-forming solutions which probably contained polysulphides, is an observed fact in geology; but the dissociation of pyrite has apparently not been noted, although certain phenomena in the vicinity of contacts would suggest this. The most distinct phenomenon which points to such a reaction is the almost constant presence of pyrrhotite in contact metamorphic shales. In such shales pyrite develops normally at some distance from the contact, while close to it, pyrrhotite is universally present and there is little, if any, pyrite. (Lindgren.) The occurrence of pyrrhotite which could be proved to have formed in this way would point to a temperature above 500°,—much higher if the dissociation occurred under considerable pressure. Pseudomorphs of pyrite after pyrrhotite do not seem to have been observed, but they would probably be readily formed by the action of polysulphides on pyrrhotite crystals. Pseudomorphs of marcasite after pyrrhotite have been described by Schöudox and Schroeder* and by Pogue.† The synthetic experiments (see p. 179) suggest that these were formed by the addition of sulphur from slightly acid solutions containing hydrogen sulphide and free sulphur in suspension.

2. The possibility of the formation of pyrrhotite from slightly acid solutions at temperatures as low as 80° has been made clear in the foregoing pages. The crystals made in this way were generally associated with crystals of pyrite and perhaps marcasite, a fact which shows how readily the former unite with sulphur. This is probably the reason why the pyrrhotite of nature never seems to form under the above conditions, for such could only occur in surface solutions where there is more or less access of air. This, with hydrogen sulphide, would give free sulphur.

3. Pyrrhotite is regarded in certain instances as a primary constituent of eruptives. Its intimate intergrowth in such cases with silicates such as augite and olivine strongly suggests the conclusion that both have separated from a common magma. Now it is well known that molten sulphides of this sort are all but immiscible with molten silicates; in other words, a system like this would separate into two layers. It would be a matter of great interest to determine whether the addition of water, aqueous sodium sulphide or even of a more complex solution

* Jahrest. Niedersachsischen geol. Vereins Hannover, p. 132, 1909.
† Proc. U. S. Nat. Mus., xxxix, 576, 1911.

would bring a two-layered system of this character to homogeneity, but at present the problem is experimentally beyond our means.

Summary.

[Including the results of Part III, as follows.]

1. The formation of iron disulphide was accomplished (1) by the action of hydrogen sulphide on ferric salts, or the action of sulphur and hydrogen sulphide on ferrous salts; (2) by the addition of sulphur from solution to amorphous ferrous sulphide or pyrrhotite; (3) by the action of soluble polysulphides on ferrous salts; (4) by the action of soluble thiosulphates on ferrous salts according to the equation $4M_2S_2O_3+FeX_2=3M_2SO_4+FeS_2+2MX+3S$. The first three methods may be generalized as *the action of sulphur on ferrous sulphide*: (*a*) in acid solutions; (*b*) in nearly neutral solutions, and (*c*) in alkaline solutions, since in (1) we may assume that ferrous sulphide first forms by the action of hydrogen sulphide on the ferrous salt, and in (3) we know that polysulphides first precipitate a mixture of ferrous sulphide and sulphur. Marcasite was obtained with certainty only by method (1); low temperatures and free acid favor its formation. A solution containing about 1 per cent of free sulphuric acid at 100° gives pure marcasite. Less acid solutions at higher temperatures give mixtures of marcasite and pyrite. The other methods give pyrite which, under certain conditions, may be mixed with amorphous disulphide. It is possible that some marcasite may be formed by method (4).

2. Marcasite and pyrite were identified in the above products: (1) By microscopic examination and crystallographic measurement. The pyrite crystals showed only the cube and the octahedron. Marcasite crystals were formed for the first time. They were commonly twinned after (110), and their habits are shown in figures 15 and 16, Pt. III. The axial ratios of the synthetic mineral are $a:b:c = 0{\cdot}7646:1:1{\cdot}2176$ and agree remarkably well with those of the natural mineral. (2) By Stokes's oxidation method, which serves also for the analysis of mixtures of the two minerals.

3. Marcasite changes to pyrite with evolution of heat. The change proceeds very slowly at 450° and is not accelerated by pressures even of 10,000 atmospheres. Marcasite is monotropic toward pyrite. This is in accord with the greater inclination of marcasite to oxidize, its assumed greater solubility, and the fact that its formation is conditioned by the composition of the solution from which it crystallizes.

4. The fact that marcasite never occurs as a primary constituent of magmas, while pyrite sometimes does, is explained

by the fact that marcasite cannot exist above 450°. The formation of pyrite in deep veins and hot springs is explained by the fact that the waters from which it came were alkaline. The marcasite of surface veins was probably formed from cold acid solutions, while mixtures of marcasite with pyrite were probably conditioned by higher temperature (up to 300°), or the presence of less acid, or both. Micro-organisms may have been active in the formation of pyrite and marcasite by giving rise to hydrogen sulphide.

5. Pyrrhotite was formed by the decomposition of pyrite or heated marcasite, or by heating iron with excess of sulphur. The dissociation of pyrite into pyrrhotite and sulphur is readily reversible. At 565° (about) pyrite and pyrrhotite are in equilibrium with the partial pressure of sulphur in H_2S, which here amounts to about 5^{mm} (data of Preunner and Schupp); at 550° in hydrogen sulphide, the pyrrhotite passes into pyrite, and at 575° the reverse action proceeds. At about 665° the evolution of sulphur from pyrite becomes rapid and a marked absorption of heat results. The pressure of the sulphur vapor here probably reaches one atmosphere.

6. Pyrrhotite is of variable composition. Its composition at any temperature depends on the pressure of sulphur vapor in which it is heated. Though it has not been found feasible to vary the temperature and pressure independently, a series of products were prepared by first decomposing pyrite and then reheating the resulting material to various measured temperatures in hydrogen sulphide and finally chilling in the same or cooling in nitrogen. The products lowest in sulphur were obtained in the latter way. These products all resemble natural pyrrhotite in physical and chemical properties. Their specific volumes vary continuously with composition and pyrrhotite is therefore to be regarded as a solid solution of sulphur in ferrous sulphide. The maximum percentage of dissolved sulphur in synthetic pyrrhotite was 6·04 per cent at 600°. By extrapolation the saturated solution at 565°, below which point pyrite forms, was estimated to be 6·5 per cent. This corresponds closely to the maximum percentage of sulphur reported in natural pyrrhotite.

7. Equilibria between pyrrhotite and the partial pressure of sulphur in dissociated hydrogen sulphide were determined at different temperatures, by sufficiently long heating and then rapid cooling. The dissolved sulphur varied under these conditions from 6·0 per cent at 600° to 2·0 per cent at 1300°. The curve shows a discontinuity at the melting temperature, at the beginning of which there is a sudden decrease in the percentage of sulphur.

8. The melting point of pure ferrous sulphide could not be exactly determined because the compound dissociates at high temperatures into its elements. By heating it in a vacuum this dissociation was placed beyond doubt, though the dissociation was so slow that the melting point could be located approximately. It may safely be put at 1170°±5°. In hydrogen sulphide, the melting temperature is raised, because the solid solution thus formed contains more sulphur than the first portion of liquid to which it melts. The limits of the melting interval cannot be determined as yet, but the maximum heat absorption falls at 1183°. In one atmosphere of sulphur vapor this temperature rises to 1187°.

9. Crystals of pyrrhotite, the measurements of which are recorded under the Crystallographic Study, were repeatedly formed at various temperatures between 80° and 225° by the action of hydrogen sulphide on slightly acid solutions of ferrous salt containing some ferric salt. The product usually contained some crystals of disulphide.

10. The crystallographic study confirms the work of Rinne and Boeke and others, that there are two crystal forms of pyrrhotite. The high temperature form, α-pyrrhotite, appears to be orthorhombic and the axial ratios vary from $a:b:c=$ 0·5793:1:0·9267 to 0·5793:1:0·9927, depending on the amount of the dissolved sulphur present (?). The habits of the crystals are shown in figs. 17, 18 and 20, Pt. III. β-pyrrhotite is hexagonal, and c varies from 0·8632 to 0·8742. The crystal habit is shown in figs. 22 and 23, Pt. III.

The crystal constants of natural pyrrhotite can not be assumed to be invariable, since the composition of the mineral is not constant, and the crystal angles of the synthetic mineral are variable. The lack of agreement among mineralogists regarding the crystal system to which pyrrhotite belongs can be explained on the theory that there are two forms of pyrrhotite.

11. Troilite is only the end member of the pyrrhotite series and not a distinct mineral species. Thus far, it has not been prepared free from metallic iron.

In conclusion, the authors wish to express their hearty thanks to Dr. Carl Alsberg and Dr. Oswald Schreiner for important references, and to Dr. F. L. Ransome, Dr. W. H. Emmons and Mr. C. A. Davis for valuable geological information, and especially to Mr. W. Lindgren, not only for placing at our disposal the generalized results of his extensive experience, but for reading this paper and making a number of important suggestions.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C., Dec. 1, 1911.

III. Crystallographic Study.

As the sulphides of iron are all opaque, the ordinary optical tests are not available and the mineralogic study is confined to the determination of the color, luster, cleavage, magnetic properties, crystal form, chemical properties, etc. Color and magnetism are important diagnostic properties of the sulphides of iron, while the crystal form and the chemical properties give positive evidence of the identity of the artificial preparations with the natural minerals. In general the synthetic iron sulphides prepared in the dry way or by the inversion of one form into another in the solid state are massive and without crystal form, and only the color, magnetic and chemical properties can be determined. The iron sulphides precipitated from solutions usually consist of a network of crystals, or of drusy crusts. Some preparations have crystals which are large enough for measurement on the Goldschmidt goniometer; most of the crystals measured are from 0·2 to 0·4^{mm} in length, though one crystal of β-pyrrhotite is about a millimeter in length, and one crystal of marcasite is even a little larger. In many of the preparations the crystals are all very minute—less than a tenth of a millimeter in length and often much less—and the crystallographic study was confined to an examination of the material under the microscope. The crystal habit, however, of each of the four minerals is characteristic, and even the minute crystals can usually be determined.

Pyrite.

In some preparations the larger crystals of pyrite are half a millimeter across and can be easily recognized with a pocket lens by their color and crystal form. Much smaller crystals can be determined by the use of the microscope. The crystals usually show both the cube and the octahedral faces, but both forms also occur alone; pyritohedrons were not observed; the faces are always much warped and very imperfect. For the several crystals measured on the goniometer, the angles were seldom over half a degree from the theoretical value, and a closer agreement cannot be expected.

Marcasite.

The color of the synthetic marcasite is identical with that of the natural mineral, but the color test is not altogether satisfactory on minute crystals, even when brightened by heating in acid. The crystal habit, however, is characteristic, and the goniometric measurements of some of the larger crystals show a very close agreement with those of the natural mineral.

The common habit of the synthetic marcasite is shown in clinographic projection in fig. 15. The crystals are twinned with the face *m* (110)* as twinning plane, they are tabular parallel to the twinning plane and elongated along the vertical axis. The prisms *m* {110}, especially the large faces parallel to the twinning plane, are deeply striated parallel to the base. The domes *e* {101} and *l* {011} are also prominent. Crystals of a second habit, which are common in some preparations, are more symmetrical in their development and less often twinned; in them the domes, *e* {101} and *l* {011}, are characteristic forms

FIG. 15.

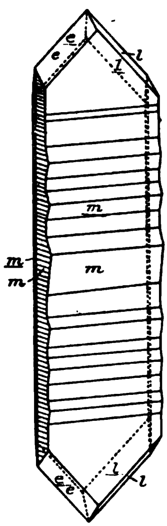

FIG. 16.

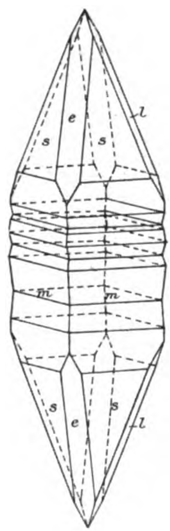

FIG. 15. Artificial marcasite showing the forms *m* {110}, *e* {101}, and *l* {011}. Twinned after (110).

FIG. 16. Artificial marcasite showing the forms *m* {110}, *e* {101}, *l* {011}, and *s* {111}.

and the striated prisms, *m* {110}, are usually prominent. The crystal represented in fig. 16 is of this habit, but the prisms and pyramids *s* {111} are more prominent than usual. Several crystals were seen under the microscope which resemble the fiveling pictured by Dana.† A preparation formed as usual, but at room temperature, consists of strings of minute crystals which have a rhombic outline under the microscope, and sometimes the obtuse angle of the rhombs is truncated by a face which is probably the prism, *m* (110).

*Throughout this paper parentheses are used to indicate crystal faces; brackets, to indicate the entire crystal form.

† System of Mineralogy, 6th edition, p. 95.

Crystals of marcasite large enough for measurement on the goniometer were found in several preparations; most of them are only a few tenths of a millimeter in length, but a few are about a millimeter long. Seven fairly satisfactory crystals from two different preparations were measured. Only one of these is not twinned. The signals were seldom sharp, blurred signals, striated zones, and vicinal faces being the rule. The faces of $\{111\}$ usually gave fairly sharp reflections, but between (111) and $(11\bar{1})$ there was a more or less complete band of signals, and that for the face (110) seldom stood out sharply from the others. In some of the tabular twinned crystals the faces of $\{110\}$ which are parallel to the twinning plane yielded bright signals, or else there were several bright signals near these faces. The reflections from the faces of $\{011\}$ were usually bright, but vicinal development often made their exact position uncertain. Between (011) and $(01\bar{1})$ there was usually a dim series of signals, but the reflection signals of the faces of $\{011\}$ did not stand out from the others. The faces of $\{101\}$ gave fairly sharp signals. In one crystal the reflections of the faces of $\{772\}$ took the place of those from $\{111\}$ at the ends of the series of signals of this zone. Most of the twinned, tabular crystals gave a dim but nearly continuous line of signals from the large faces (110) through the face (011) and the corresponding face $(0\bar{1}\bar{1})$ to $(\bar{1}\bar{1}0)$. The faces $\{10\bar{1}\}$ of both individuals lie on this zone, whose symbol is $h+l=k$. It is poorly developed on the untwinned crystal.

Crystal angles of synthetic marcasite.—Of the seven crystals to be described, the first five were from a preparation of October 16, 1908, and were formed by the action of H_2S on an acid solution of $FeSO_4$ for four days at a maximum temperature of 300°. The crystals of this preparation are all of the habit shown in fig. 15. Crystals 6 and 7 were from a preparation of October 28, 1908, and were formed at a maximum temperature of 220°. The common habit of the crystals of this preparation is shown in fig. 16, but the pyramids and prisms are often less prominent; there are some twinned crystals similar to those shown in fig. 15.

Table IX lists the weighted average of the angles measured for each crystal, the crystal constants of synthetic marcasite, and the corresponding constants of the natural mineral as given by Gemacher and Goldschmidt.

The agreement shown by Table I between the angles and axial ratios of natural marcasite and those of the synthetic mineral is very good. Both commonly show twinning with (110) as twinning plane, and both have the two unit domes and the pyramids as common faces. The base, however, which is

TABLE IX.

Crystal angles measured on synthetic marcasite.

No. of Crystal	No. of meas.	Polar angle of (011)	No. of meas.	Polar angle of (111)	No. of meas.	Polar angle of (101)	No. of meas.	(110) (010)	No. of meas.	Angle between twin after (110)	No. of meas.	Polar angle of (772)
1	1	50° 58′		....		....	2	52° 41′	3	74° 42′		....
2	2	50° 40′		....	2	58° ±	1	52° 12′	1	74° 33′	3	81° 50′
3	3	50° 44′		....		....	6	52° 36′	2	74° 20′	6	81° 48′
4	6	50° 18′		....		....	6	52° 35′	1	75° 12′		...
5	5	49° 55′	8	63° 40′	3	57° 27′	5	52° 34′	3	74° 47′		....
6	2	49° 55′	6	63° 29′	2	58° 10′	5	52° 38′		....		....
7	4	50° 40′	6	63° 22′	2	57° 50′	4	52° 28′	2	75° 18′		....
Weighted av....		*50° 27′*		*63° 29′*		*57° 48′*		*52° 35′*		*74° 49′*		*81° 48′*
Computed......		50° 36′		63° 29′		57° 52′		52° 35½′		74° 49′		81° 53½′
Gemacher*.....		50° 36′		63° 30′ 54″		57° 55′ 59″		52° 41′		....		....
Goldschmidt†...		50° 29′		63° 30′		57° 59′		52° 50′		....		....

$a : b : c = 0{\cdot}7646 : 1 : 1{\cdot}2176$ Larsen, synthetic marcasite

$a : b : c = 0{\cdot}762256 : 1 : 1{\cdot}216698$ Gemacher*

$a : b : c = 0{\cdot}7580 : 1 : 1{\cdot}2122$ Goldschmidt†

$a : b : c = 0{\cdot}75241 : 1 : 1{\cdot}18473$ Hausmann

$a : b : c = 0{\cdot}766172 : 1 : 1{\cdot}23416$ Sadebeck

* Natural marcasite, Gemacher, Zs. Kryst., xiii, 242, 1888.

† Natural marcasite, Goldschmidt, Winkeltabellen, Berlin, 1897.

usually prominent in the natural mineral, was not observed on the synthetic crystals, while the prism zone is often more prominent on the artificial crystals. The natural mineral is described as having the brachydomes and pinacoids deeply striated parallel to the edge (010) (001); the synthetic mineral is similarly striated, the pyramid and prism zones are even more prominently striated parallel to the base, and the zone $h + l = k$ on some of the crystals is a more or less continuous series of faces due to striations.

Pyrrhotite.

The experiments of Rinne and Bœke* show an inversion in FeS with 7 per cent, the maximum amount, of dissolved iron at 138°. On decreasing the amount of dissolved iron to 5 per cent the absorption of heat takes place between 90° and 98°. Although they were not able to observe a heat absorption in FeS with less than 5 per cent of dissolved iron or in natural pyrrhotite, they state that the inversion takes place but is too sluggish to be observed. Ferrous sulphide with a little carbon showed the inversion at 134·5°, while meteoric troilite with a little carbon inverted at about 143°.

The present crystallographic study tends strongly to confirm the work of Rinne and Bœke. The low temperature form or β-pyrrhotite appears to be hexagonal, while the high temperature form or α-pyrrhotite appears to be orthorhombic. The measured interfacial angles for the two forms are near together and the fact that these angles vary with the amount of sulphur in excess of that required for FeS, together with the impossibility of determining the chemical composition of the measured crystals, makes a comparison of the crystal constants of the two forms impossible. However, the crystal habit, the twinning, and the development of the faces on the two forms afford good evidence for the view that they belong to different crystal systems.

The color of the synthetic pyrrhotite is similar to that of the natural mineral. That prepared by melting iron and sulphur together is a little darker and has more of a grayish cast than the natural mineral. The crystals from some preparations of α-pyrrhotite are only slightly magnetic while those from others are strongly so. The crystals always show polarity with the poles along the a-axis. The poles for β-pyrrhotite are along the c-axis in the one crystal observed.

α-Pyrrhotite.

Twenty-two fairly satisfactory crystals of α-pyrrhotite, representing four different preparations, were measured on the

* Zs. anorg. Chemie, liii, 338–343, 1907.

goniometer. The crystals are almost certainly orthorhombic in symmetry, although the angles in the prism zone are very nearly 60°. In the following discussion, the crystals are treated as orthorhombic. The crystals are usually twinned

FIG. 17.

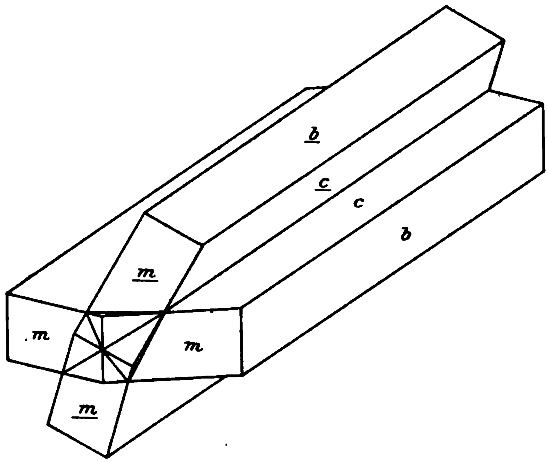

FIG. 17. Artificial *a*-pyrrhotite showing the forms *m* {110}, *b* {010}, and *c* {001}. Twinned after (023).

FIG. 18.

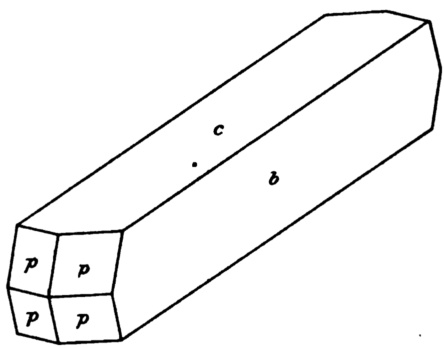

FIG. 18. Artificial *a*-pyrrhotite showing the forms *b* {010}, *c* {001}, and *p* {111}.

with the twinning plane (023); one crystal is twinned only after (021), and two crystals are twinned after both laws. The twinned crystals are tabular parallel to the base and elon-

gated in the direction of the *a*-axis. The untwinned crystals are also nearly always much elongated along the *a*-axis, and have as their principal forms {001}, {010}, {111}. Tabular crystals of hexagonal shape are rare.

Crystals A to H are from two different preparations formed by the action of H_2S on an acid solution of $FeSO_4$ at a maximum temperature of 225° C. They are about $0{\cdot}3 \times 0{\cdot}15 \times 0{\cdot}05^{mm}$ in dimensions. Most of the crystals are tabular parallel to the base and elongated along the *a* axis; they are twinned after (023); {001}, {010}, and {110} are

FIG. 19.

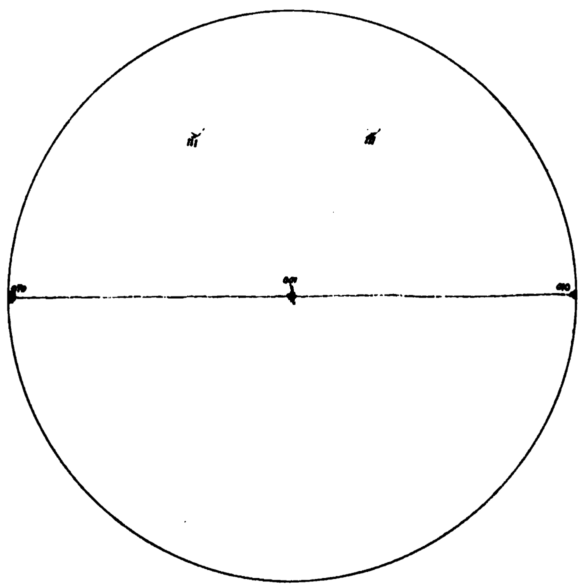

FIG. 19. Stereographic projection of a simple crystal of *a*-pyrrhotite showing the development of the striation and vicinal faces.

the dominant forms. Fig. 17 shows one of these crystals. Crystal H simulates a tabular hexagonal crystal; it is not twinned and is bounded by the forms {001}, {010}, {110}, {011}, {112}, {021}, and {111}. Crystals of this type are uncommon.

A third preparation was formed at about 200° C. The inside tube contained 3 g. $FeCl_2$, 1^{cc} 20 per cent HCl, and 25^{cc} boiled H_2O. After heating at about 200° C. for several days, the sealed tube was allowed to stand at room temperature from June 16, 1909 to March 23, 1910. There was a considerable

yield of pyrrhotite crystals. They are strongly magnetic and show polarity with the poles along the *a* axis. Many of them are about 0·3^{mm} in length and about a fifth as thick and broad. Twinning is rare and the base resembles a hexagon much elongated along one diameter and delicately striated parallel to the six sides. There are a very few hexagonal tablets and twinned crystals similar to those of preparations 1 and 2. The six measured crystals, I to N, are all similar in habit to the crystal

Fig. 20.

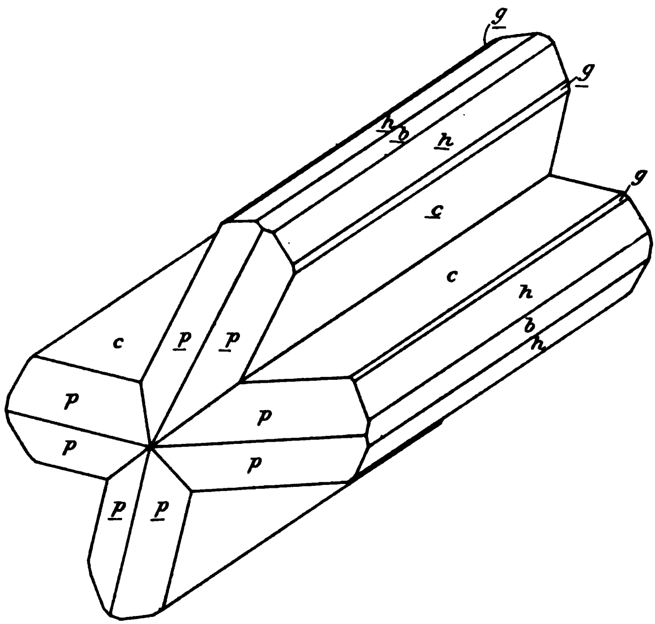

Fig. 20. Artificial *α*-pyrrhotite showing the forms *c* {001}, *b* {010), *p* {111}, *h* {021}, and *g* {011}. Twinned after (021).

shown in fig. 18, and the dominant forms are {001}, {010}, and {111}. One crystal showed also the form {021} poorly developed, and another crystal showed {091}. Fig. 19 is the stereographic projection of crystal I. The crystals were mounted along the *a* axis. They did not, in general, give sharp signals and measured angles between (001) and (010) were in some cases out as much as 2°; while the measurements for the faces {111} were only a little better.

A fourth preparation was formed by the action of H_2S on a solution of acid FeCl at a maximum temperature of 210°. Nearly all of the crystals are tabular parallel to the base and

elongated along the *a* axis. Several of them are 0·5^{mm} in length. Out of seven crystals measured, one is twinned after the law: twinning plane (021); three are twinned after the law: twinning plane (023); two after both laws, and one crystal is an untwinned hexagonal tablet. The crystals resemble the untwinned crystals of lot 3 in that the dominant forms are {001}, {010}, and {111}, but {021}, {011}, {0.1.20}, {110}, and {112} were also recognized. Fig. 20 represents one of these crystals twinned after (121). Fig. 21 is the stereographic projection of crystal U, which is twinned after both (023) and (021). One of the individuals of the twin after (023) is poorly developed on the part of the crystal shown.

FIG. 21.

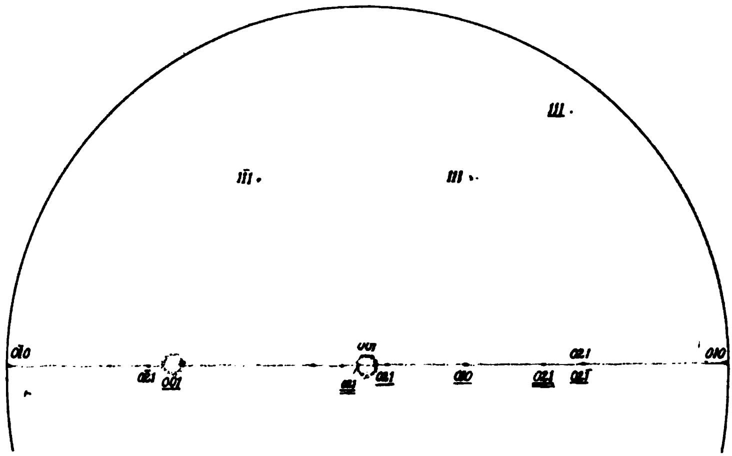

FIG. 21. Stereographic projection of a crystal of *a*-pyrrhotite twinned after both (021) and (023). The half of the crystal represented on the projection shows few of the faces of one of the individuals after (023). The faces of the crystal twin after (021) are underscored once, those of the twin after (023) twice.

Table X gives a summary of all the crystals of *a*-pyrrhotite which were measured. The designation of the crystal is given in column one and the number of the preparation from which it came in column two. Column three lists the faces recognized on the crystal, and column four gives the average of the angle between the faces (110) and (010). The eight succeeding columns give the weighted averages of the measured interfacial angles each followed by the value of p_0 computed from that angle. Next to the last column lists the weighted averages of the constant p_0 which is equal to the vertical axis, *c*. The final column gives all measured angles not listed in any of the previous columns.

A comparison of the different values of p_0 with the average value, c, for any crystal shows that the difference is greater than 2 per cent only for crystal A, and in this case the angle from which p_0 was computed was so unreliable that it was not considered in computing the average. In all cases where the angle from which any p_0 was computed seemed to be reliable the difference between p_0 and c is less than 1 per cent of c. An error as large as 1 per cent in c may, therefore, be regarded as exceptional. One possible exception is crystal I, as the measurements on it were unsatisfactory and it has, therefore, been discarded in the discussion to follow. If, however, we compare the value of c for the different crystals we find a maximum difference of 0·0660 between crystals M and T or a difference of nearly 7 per cent of their mean value. Moreover, the two extremes are neither exceptionally high nor exceptionally low but the other crystals are pretty evenly distributed between them. It seems certain, therefore, that the crystal constants of α-pyrrhotite vary considerably in accord with the variable composition of the mineral.

A further study of Table II shows that while the crystals of a given preparation show a considerable difference in the constant, c, yet those of preparation 3 are uniformly high, those of preparation 4 generally low, and those of preparation 1 and 2 intermediate. Unfortunately it was not found possible to determine the relation between the value of c and the chemical composition, as, even were any of the crystals large enough for an analysis, it is probable that they are built up of successive shells of different composition.

No consistent variation in the angle (100) (110) was recognized but it probably varies with c. The measurements were usually not good but the average value of 59° 55′ is probably within 15′ of the true value. Computing the axial ratios of α-pyrrhotite for the limiting values given by crystals M and T we have: $a:b:c$ 0·5793 : 1 : 0·9267 to 0·5793 : 1 : 0·9927. It is probable that the limits are considerably greater than this. Table XI lists the observed faces and the interfacial angles as computed from the above values of the axial ratios.

The symmetry and crystal constants of α-pyrrhotite.— The evidence that α-pyrrhotite is orthorhombic in symmetry is good, although it may not be conclusive. The angles in the prism zone were not proven to differ from sixty degrees, but the habit of the crystals consistently indicates orthorhombic rather than hexagonal symmetry. A very few crystals resembled hexagonal tablets. Nearly all of the crystals of the first two preparations were developed much like the crystal shown in fig. 17, although small domes and pyramids were found on many of the measured crystals. The habit and

TABLE X.—SUMMARY OF CRYSTAL

Crystal	No. of Preparation	Faces represented	(010) (110)	Angle betw. basal pinacoids of twin after (023)	p_o	Angle betw. basal pinacoids of twin after (021)	p_o	(001) (021)
A	1	(001) (010) (110) (112)	60° ±	66° 30′	0·9834	......	......	......
B	1	(001) (010) (110)	59° 32′	65° 35′	0·9850	......	......	......
C	1	(001) (010) (110)	59° 50′	65° 7′	0·9578	......	......	......
D	2	(001) (010) (110) (100) (011) (023)	60° 10′	65° 27′	0·9639	......	......	....
E	2	(001) (010) (110)	59° 57′	63° 59′	0·9376	......	......	......
F	2	(001) (010) (111) (221)	60° ±	64° 5′	0·9388	......	......	......
G	2	(001) (010) (110) (992)	59° 57′	65° 57′	0·9732	......	......	......
H	2	(001) (010) (110) (021) (111) (011) (112)	60° ±	......	......	......	......	62° 44′
I	3	(001) (010) (111)	60° 22′ ±	......	......	......	......	......
J	3	(001) (010) (111) (091)	59° 56′	......	......	......	......	......
K	3	(001) (010) (111)	60° 5′	......	......	......	......	......
L	3	(001) (010) (111)	59° 36′	......	......	......	......	......
M	3	(001) (010) (111)	60° 4′	......	......	......	......	......
N	3	(001) (010) (021) (111)	59° 59′	......	......	......	......	63° 15′
O	4	(001) (010) (021) (111) (011) (112)	59° 53′	65° 30′	0·9648	......	......	62° 31′
P	4	(001) (010) (021) (111)	60° ±	......	......	......	......	62° 14′
Q	4	(001) (010) (021) (111) (071)	60° ±	......	......	55° 18′	0·9545	62° 19′
R	4	(001) (010) (110) (021) (111) (0·1·20)	60° ±	65° ±	......	......	......	62° 26′
S	4	(001) (010) (110) (021) (111) (011)	59° 44′	66° 10′	0·9772	......	......	62° 18′
T	4	(001) (010) (021) (111) (011)	60° ±	62° 50′	0·9160	52° 25′ ±	......	61° 38′
U	4	(001) (010) (021) (111) (011) (1.1.34)	60° 30′ ±	64° 40′	0·9495	55° 30′	0·9503	62° 8′

the development of different faces in the zone (*0 k l*) from those in the zone (*h h l*) strongly indicate orthorhombic symmetry. The crystals of the third preparation were, with few exceptions, developed as is the crystal shown in fig. 18. The development of the zonal and vicinal faces is shown in fig. 19, which is a stereographic projection of crystal I. The other crystals of this lot are much like this, although the striations of the zone (*0 k l*) are not usually so prominent. The crystals

Measurements of α–Pyrrhotite

p_o	(001) (111)	p_o	(001) (011)	p_o	(001) (112)	p_o	Average $p_o=c$.	Other measured angles
-----	------	-----	------	-----	43° 50′	0·9610	0·9834	-----------------
-----	------	-----	------	-----	------	-----	0·9850	-----------------
-----	------	-----	------	-----	------	-----	0·9578	-----------------
-----	------	-----	44° 10′	0·9713	------	-----	0·9639	(001) (021)=32° 27′
-----	------	-----	------	-----	------	-----	0·9376	-----------------
-----	61° 48′	0·9372	------	-----	------	-----	0·9380	(001) (221)=74° 59′
-----	------	-----	------	-----	------	-----	0·9732	(001) (992)=83° 41′
0·9701	62° 44′	0·9750	43° 59′	0·9646	43° 59′	0·9675	0·9725	-----------------
-----	63° 24′	1·0035	------	-----	------	-----	1·0035±	-----------------
-----	63° 1′	0·9878	------	-----	------	-----	0·9878	(001) (091)=83° 17′
-----	62° 55′	0·9827	------	-----	------	-----	0·9827	-----------------
-----	62° 32′	0·9667	------	-----	------	-----	0·9667	-----------------
-----	63° 9′	0·9927	------	-----	------	-----	0·9927	-----------------
0·9920	63° 4′	0·9891	------	-----	------	-----	0·9891	-----------------
0·9614	62° 34′	0·9681	43° 51′	0·9607	44° 12′	0·9772	0·9669	-----------------
0·9497	62° 14′	0·9545	------	-----	------	-----	0·9521	-----------------
0·9530	------	-----	------	-----	------	-----	0·9530	(001) (071)=81° 40′
0·9578	------	-----	------	-----	------	-----	0·9578	(001) (0.1.20)=2° 42′
0·9524	62° 40′	0·9772	43° 50′	0·9601	------	-----	0·9660	-----------------
0·9262	61° 58′	0·9437	43° 10′	0·9380	------	-----	0·9267	-----------------
0·9456	62° 10′	0·9517	------	-----	------	-----	0·9485	(001) (1.1.34)=3° 10′

of the fourth preparation are usually twinned, and the common habit of these crystals is shown in fig. 20. This crystal is twinned after (021) and the crystals which are twinned after (023) are similar, except for the twinning law. These crystals are also elongated along the *a* axis and show a very different development in the zone (*0 k l*) from that in the zone (*h h l*). Fig. 21, which is a stereographic projection of crystal U, shows the development of the zonal and vicinal faces. Several other

Table XI.—Computed interfacial angles of a-pyrrhotite for different values of the axial ratios.

	$c = 0{\cdot}9267$	$c = 0{\cdot}9927$
(001) (011)	42° 49′	44° 47′
(112)	42° 42′	44° 40′
(021)	61° 39′	63° 16′
(111)	61° 36′	63° 13′
(010)	90° 0′	90° 0′
(110)	90° 0′	90° 0′
(100)	90° 0′	90° 0′
(023)	31° 42′	33° 30′
(221)	74° 52′	75° 50′
(010) (110)	59° 55′	59° 55′
(100) (100)	90° 0′	90° 0′
Angle between twins after (023)	63° 24′	67° 0′
Angle between twins after (021)	56° 42′	53° 28′

preparations were made up largely of crystals of high-temperature pyrrhotite, and, although no measurable crystals were found, the microscopic study showed that they were very similar in habit to the measured crystals. On the other hand, the crystals from the three preparations which were formed at 100° C. and below, invariably had a very different habit (p. 231).

β-Pyrrhotite.

Three crystals of pyrrhotite formed below the inversion temperature were measured. They were each from a different preparation and should give a fair idea of the crystal habit and crystal constants of β-pyrrhotite. Their habit and the measured angles afford good reasons for supposing that β-pyrrhotite is hexagonal. The most prominent faces recognized were those of $m\,\{10\bar{1}0\}$ and $z\,\{20\bar{2}1\}$, but those of $c\,\{0001\}$ were rather prominent on one crystal, and the vicinal form $z_a\,\{16.0.\bar{16}.7\}$ on two crystals; the faces of the form $x\,\{50\bar{5}1\}$ were subordinate on one crystal. All three of the crystals were twinned with $(10\bar{1}1)$ as the twinning plane, giving cruciform twins with an angle of approximately 90° between the two individuals. Figures 22 and 23 are clinographic projections of the two habits of the crystals.

The best crystal came from a preparation which was formed by heating for 8 days at a maximum temperature of 80° C. a

sealed glass tube which contained a dilute solution of $FeSO_4$ saturated with H_2S at 0° C. The yield of β-pyrrhotite was small and consisted of the measured crystal which was about 1^{mm} in length, a crystal about half as large and a few crystals less than $0{\cdot}2^{mm}$ in length. All were twinned and otherwise

FIG. 22.

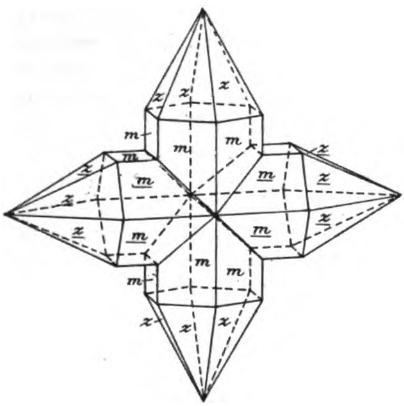

FIG. 23.

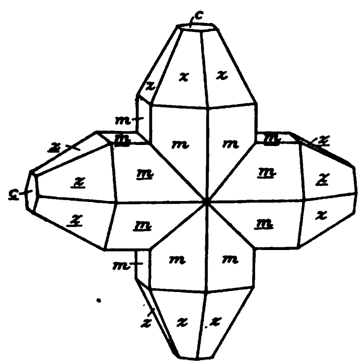

FIG. 22. Artificial β-pyrrhotite showing the forms m $\{10\bar{1}0\}$ and z $\{20\bar{2}1\}$. Twinned after $(10\bar{1}1)$.

FIG. 23. Artificial β-pyrrhotite showing the forms m $\{10\bar{1}0\}$, z $\{20\bar{2}1\}$, and c $\{0001\}$. Twinned after $(10\bar{1}1)$.

similar to the measured crystal. This crystal, which was mounted on the goniometer along the c-axis of one of the individuals, gave blurred and multiple signals, but it was not striated, and most of the faces could be located to within about ten minutes. The only forms developed were the prisms $\{10\bar{1}0\}$ and the steep pyramids $\{20\bar{2}1\}$. Figure 22 is the clinographic projection of the crystal. Six fairly good measurements of the angle $(20\bar{2}1) \wedge (20\bar{2}\bar{1})$ gave values of 53° 29′, 53° 30′, 53° 31′, 53° 6′, 53° 15′, 53° 41′, averaging 53° 22′; hence the polar angle of $(20\bar{2}1)$ is 63° 19′. Two good measurements of the angle between $(10\bar{1}0)$ and $(\underline{10\bar{1}0})$ were 89° 41′ and 89° 49′, averaging 89° 45′. The twinning plane is therefore $10\bar{1}1$. The angles measured between the prisms were never over 30′ from 60°.

The conditions of formation of the second crystal were similar to those of the first but the maximum temperature was about 100°* and the tube was allowed to stand at room tem-

*** We do not know the inversion temperature of FeS with an excess of sulphur and can not, therefore, be certain that this and the following crystals were formed below that temperature. Their habit, however, is evidence that they belong to the low temperature form.**

perature for about three months before opening. A considerable number of small, twinned crystals similar to the measured crystal and in no case over $0{\cdot}15^{mm}$ in length were formed. The measured crystal was similar in its development to crystal 1, except that the pyramids were somewhat striated parallel to the base and $\{16.0.\overline{16}.7\}$ was the dominant pyramid. The reflections were not quite so good as those of the first crystal. Six measurements of the polar angle of $(16.0.\overline{16}.7)$ varied from 66° 0′ to 66° 31′, averaging 66° 18′. The signals for the face $(20\overline{2}1)$ did not stand out sharply from the other signals of its zone, but three measurements of the angle between the points where the strings of signals for the pyramid zones of the two individuals intersected gave 52° 47′, 53° 32′, and 52° 34′, averaging 52° 58′. The polar angle of $(20\overline{2}1)$ is, therefore, 63° 31′. One good measurement of the angle between the prism faces of the two individuals was 90° 14′. The angles in the prism zone may differ as much as 30′ from 60°.

The third preparation was formed as was the second but the crystals differed in that the base was rather prominent and the form $\{50\overline{5}1\}$ was present. The habit of these crystals is shown in fig. 23. The measured crystal which was less than $0{\cdot}2^{mm}$ in length gave rather poor signals, and many of the faces were very poor or missing. There was a continuous line of signals from the prisms to the pyramids $(20\overline{2}1)$ and the angle between the intersections of these zones belonging to the two individuals measured 52° 34′ and 52° 0′, averaging 52° 20′. Therefore the polar angle of $(20\overline{2}1)$ is 63° 50′. The angle between the bases of the two individuals measured 90° 7′. Three measurements of the polar angle of $(16.0.\overline{16}.7)$ averaged 66° 25′ with a maximum deviation of 19′. Five measurements of the polar angle of $(50\overline{5}1)$ averaged 78° 55′ with a maximum deviation of 26′. The angles between the prisms could not be measured accurately but they differed from 60° by less than 20′.

The data for the three measured crystals of β-pyrrhotite are assembled in Table XII. The table shows the principal interfacial angles as measured on each crystal and as computed from the average value of the constant p_0, the faces observed on each crystal and the value of the vertical axis c. There is a close agreement between the measured and the computed angles and it seems certain that the difference in the value of p_0 for the different crystals represents an actual difference in the crystal constants. Their difference is easily accounted for, as the amount of sulphur in pyrrhotite varies considerably.

A comparison of the two forms of pyrrhotite.—The following criteria for distinguishing between the two forms of

pyrrhotite applied to all of the artificial crystals which were examined and should serve as more or less reliable means of distinguishing between the two forms in both natural and synthetic crystals:

1. The habit of β-pyrrhotite is hexagonal and the dominant forms are the prism, and a steep pyramid, and sometimes also the base (figs. 22 and 23). α-pyrrhotite, on the other hand, is always tabular parallel to the base; a few of the crystals appear to be hexagonal, but most of them are much elongated in the direction of the a axis and the orthorhombic symmetry is further shown by the common association of the forms $\{001\}$, $\{100\}$, and $\{111\}$ (figs. 17, 18 and 20).

2. The low temperature form (β) is almost invariably developed as cruciform twins with an angle of about 90° between the two individuals (twinning plane $10\bar{1}1$), while the high temperature form (α) is usually twinned after (023) with the two individuals at about 65° to each other, and sometimes also after (021) with the two individuals at about 55° to each other.

3. The constant p_0 for the measured crystals of β-pyrrhotite varied from 0·9967 to 1·0100, while for α-pyrrhotite it varied from 0·9267 to 0·9927. While crystals for which the value of p_0 was approximately 1·0000 were found in both

TABLE XII.

Crystal data of β-Pyrrhotite.

	Crystal 1		Crystal 2		Crystal 3	
	Observed	Computed $p_0=0·9967$	Observed	Computed $p_0=1·004$	Observed	Computed $p_0=1·01$
Polar angle of $(20\bar{2}\bar{1})$	63° 19′	63° 19′	63° 31′	63° 32′	63° 50′	63° 40′
Angle between twins	89° 45′	89° 42′	90° 14′	90° 14′	90° 7′	90° 34′
Polar angle of $(50\bar{5}\bar{1})$	....	....	....	....	78° 55′	78° 48′
Polar angle of $16.0.\bar{16}.7)$	....	....	66° 18′	66° 27′	66° 25′	66° 35′
Faces	$(10\bar{1}0)$ $(20\bar{2}1)$		$(10\bar{1}0)$ $(20\bar{2}1)$ $(16.0.\bar{16}.7)$		$(10\bar{1}0)$ $(20\bar{2}1)$ $(16.0.\bar{16}.7)$ $(000\bar{1})$ $(50\bar{5}1)$	
c	0·8632		0·8695		0·8742	

forms and the unknown limiting values would introduce a greater ambiguity, yet crystals for which p_0 is considerably less than 1·0000 are likely to be α-pyrrhotite while those for which p_0 is considerably greater than 1·000 are probably β-pyrrhotite.

Natural Pyrrhotite.

Pyrrhotite has generally been considered hexagonal, but as early as 1878 Streng* suggested that it was orthorhombic and isomorphous with sternbergite. However, in 1882 he† concluded that the mineral was hexagonal from a study of the crystal form, etch figures, heating curve, and magnetic properties. Vrba,‡ Frenzel,§ and Dom Pedro von Sachsen-Coburg‖ measured crystals whose angles indicated orthorhombic symmetry. Crystals associated with limestone containing garnets are described by Roth¶ as elongated along a horizontal axis and hence orthorhombic in habit. Nicol** described crystals with a "decided orthorhombic appearance." Recently Weiss†† studied the magnetic properties of pyrrhotite and concluded that it was probably monoclinic but that it could not have a higher symmetry than orthorhombic. Kaiser‡‡ concluded, from a study of magnetic and other properties, that the mineral occurred in twinned orthorhombic crystals.

There has also been a lack of agreement in the measured angles and length of the vertical axis. Table XIII gives the important crystal data for the eleven measured crystals of natural pyrrhotite which seemed to be most reliable. The first column contains the name of the author; the second, the observed faces in the order of their prominence on the crystal giving the hexagonal symbol assigned by Dana; the third column gives the habit of the crystal; the fourth column, the most probable value of p_0. The occurrence and associated minerals are listed in the fifth column. The values for the constant p_0 are reliable only for the crystals of Busz, Nicol, Seligmann, Kenngott, Rose, and perhaps Shephard. The crystal of D'Achiardi gave values of p_0 ranging from 0·9658 to 1·0240 depending on which pyramid was used in the calculation. That of Dom Pedro gave no good measurements. The two crystals of Streng and the one of Dana afforded measurements on only one pyramid and the value of p_0 depends upon the symbol assigned to it.

* Jahrb. Min., p. 797, 1878.
† Jahrb. Min., i, p. 183, 1882.
‡ Zs. Kryst. Min., iii, p. 190, 1879.
§ Min. Petr. Mitt., iii, 297, 1881.
‖ Min. Petr. Mitt., x, 451, 1888.
¶ Z. Kryst. Min., ix, 309, 1884.
** Zs. Kryst. Min., xxxi, 53, 1899.
†† Jour. de Phys., pp. 469 and 829, 1905; Centralbl. Min., p. 338, 1906.
‡‡ Centralbl. Min., p. 261, 1906.

TABLE XIII. MEASURED CRYSTALS OF NATURAL PYRRHOTITE.

Author	Faces	Habit	p_o	Occurrence and associations
1. Busz	(0001) $(10\bar{1}2)$ $(10\bar{1}0)$	Tabular (0001)	0·9407	Andreasburg. Crystals on calcite.
2. Nicol	(0001) $(10\bar{1}0)$ $(20\bar{2}1)$ $(40\bar{4}1)$ $(10\bar{1}1)$	Decided rhombic appearance Tabular after (0001)	0·946	Fontenac County, Canada. Calcite apatite, pyrite.
3. Seligman ..	(0001) $(10\bar{1}0)$ $(40\bar{4}1)$ $(10\bar{1}1)$	Tabular after (0001)	0·9528	Cyclopean Isle. In analcite basalt with molybdenite, etc.
4. Kengott ...	(0001) $(10\bar{1}0)$ $(20\bar{2}1)$	....	0·9995	Kongsberg, Norway.
5. Streng	(0001) $(10\bar{1}0)$ $(20\bar{2}1)$	....	1·1195 ?	Kongsberg, Norway.
6. D'Achiardi	(0001) $(10\bar{1}0)$ $(20\bar{2}1)$ $(40\bar{4}1)$ $(60\bar{6}1)$	Tabular (0001)	1·000±	Bottino. On argentiferous galena.
7. Rose	$(20\bar{2}1)$ (0001) $(10\bar{1}0)$ $(12\bar{1}0)$ $(24\bar{2}1)$ $(10\bar{1}1)$	....	1·002	Meteorite. Augite and feldspar.
8. Shephard ..	(0001) $(20\bar{2}1)$ $(10\bar{1}0)$ (?)	....	1·0029	Meteorite.
9. Dana (E. S.)	$(20\cdot0\cdot\bar{20}\cdot3)$?, (0001)	Twinned after $(10\bar{1}1)$	1·0035	Elizabethtown, Ontario. Pyrite, talc, calcite, plagioclase, etc. Magnetic poles at sides of crystals in (0001).
10. Dom Pedro Augusto von Sachsen Coburg	(0001) $(10\bar{1}0)$ $(10\bar{1}1)$ $(40\bar{4}1)$	Tabular after (0001)	1 0412±	Minas Geraes, Brazil. Gold vein with pyrite, arsenopyrite, chalcopyrite, albite, calcite, apatite, cronstedtite, scheelite, etc.
11. Streng	$(10\bar{1}0)$ $(10\bar{1}2)$	....	1·0972	Chanarcillo, Chile.

1. N. Jahrb. Min., i, 124, 1895.
2. Zs. Kryst. Min., xxxi, 53, 1899.
3. Zs. Kryst. Min., xi, 343, 1886.
4. Ber. Ak. Wien, ix, 575, 1852.
5. N. Jahrb. Min., 925, 1878.
6. Proc. Soc. Tosc. Sc. Nat. Pisa, xiii, 140, 1903.
7. Pogg. Ann., iv, 180, 1825.
8. This Journal, xvi, 201, 1829.
9. Ibid., xi, 386, 1876.
10. Min. Petr. Mitt., x, 451, 1888.
11. Loc. cit.

The results of the different investigations are brought into agreement by the recognition of the two forms of pyrrhotite and also of the change in p_0 with a change in the composition of the mineral. The early view of Streng* that pyrrhotite is orthorhombic and belongs to the chalcocite group holds true for α-pyrrhotite, while β-pyrrhotite is hexagonal. Further investigation may show that other members of these groups are dimorphic.

A further study of Table XIII shows that most of the eleven crystals were probably formed as α-pyrrhotite. Crystals 1 to 3 have low values for p_0, tabular habits, and crystal 3, at least, has an association which would indicate the high temperature form. Crystal 2, in particular, is described as having a "decided orthorhombic appearance" and the orthorhombic axis is shown by the elongation along it and the development of the form {221} but not {041}, and of {011} but not {112}. Crystals 4 and 5 from Kongsberg might belong to either form, but their tabular habit suggests α-pyrrhotite. Crystal 6 has the tabular habit of α-pyrrhotite. Crystal 10 has a tabular habit and is, in addition, associated with minerals which indicate the high temperature form. The occurrence of crystals 7 and 8 in meteorites places them as α-pyrrhotite. The hexagonal development and the twinning of crystal 9 indicate β-pyrrhotite, but the association with feldspar, etc., and the position of the magnetic poles are not consistent with this view.

Any list of the faces which have been found on α-pyrrhotite will be somewhat uncertain since some of the measured crystals might belong to either form, and, besides, the variable character of p_0 makes it impossible to assign a symbol to some of the measured pyramids. The following list omits doubtful faces and marks with a star those found only on synthetic crystals.

c (001)	*f* (012)	*j* (061)	*r* (221)
b (010)	*e* (023)*	*n* (201)	*s* (331)
a (100)	*g* (011)	*q* (114)	*u* (623)
m (110)	*h* (021)	*v* (112)	
l (310)	*i* (041)	*p* (111)	

* Loc. cit.

ART. XXI.—*Some Relations between Gravity Anomalies and the Geologic Formation in the United States;* by WILLIAM BOWIE.*

IN the report of an investigation of the effect of topography and isostatic compensation on the intensity of gravity, which will soon appear as a Coast and Geodetic Survey publication, there are shown certain relations between the signs of the gravity anomalies and the geologic formations on which are located the 89 gravity stations considered. There are now available 35 additional stations, making 124 in all, and it is proposed in this paper to give the results of an additional study of the relations between the anomalies and the surface geologic formations, which confirm the earlier unpublished conclusions.

The anomaly of gravity, which is used in this paper, is the difference between the observed gravity and the theoretical gravity for the latitude of the station, corrected for elevation, and for the effect of the topography and its isostatic compensation. The isostatic compensation is assumed to be complete under every separate portion of the earth's surface. If the surface density at the station is 2·67, which was that used in the computations, and the densities of the successive layers in the earth's crust are normal (except as they may be affected by the compensation), and if the isostatic compensation of the topography is complete and uniformly distributed from the surface to a depth of 114 kilometers, then the anomaly will be zero. It is assumed that every part of the surface at a depth of 114 kilometers below sea level has equal pressure at all points and, consequently, is in a state of hydrostatic equilibrium. An anomaly at a station, different from zero, shows a departure from normal conditions. If the anomaly is positive, the observed is greater than the theoretical gravity; and the reverse is the case for negative anomalies.

The computations are based upon the theory of complete compensation of the separate topographic features; the compensation being uniformly distributed to a depth of 114 kilometers. It is reasonably certain that each topographic feature is not completely compensated locally, and that the compensation is not distributed uniformly to a depth of 114 kilometers. But the gravity operations prove that the average condition over areas of large extent approximate very closely that of complete local isostatic compensation, uniformly distributed to a depth of 114 kilometers. They show that the United States

* Read before the Geological Society of America, at Washington, D. C., December 30, 1911, by William Bowie, Inspector of Geodetic Work, U. S. Coast and Geodetic Survey.

is not held up by the rigidity of the earth's crust, and that no area within the United States, as large as the State of Ohio, for instance (41,000 square miles), is so supported.

On the whole, the gravity anomalies in the United States are very small, and there is, apparently, no connection between the size and sign of the anomaly and the character of the topography. On the other hand, there is, apparently, a relation between the surface geologic formation and the anomalies.

Of the 124 stations in the United States, 10 are in areas of Precambrian formation, 31 are in Paleozoic, 20 are in Mesozoic, 30 are in Cenozoic, 11 are in Effusive or Intrusive, and 22 are unclassified. The geological map of North America, by Gannett and Willis, of 1906, was used in making decisions as to the geologic formation at the stations.

Those stations were left unclassified which plotted on the map near the dividing line between two formations, or when in such areas as at Ely and Winnemucca, Nevada, where there are rocks of several geologic ages within a few miles of the station.

The table shown below gives the means of the anomalies in dynes (or centimeters) with and without regard to sign, for the several groups of gravity stations. The average gravity in the United States is about 980 dynes or centimeters.

Geologic Formation	Number of Stations	Mean with regard to sign	Mean without regard to sign
Precambrian	10	+·016	·026
Paleozoic	31	—·003	·019
Mesozoic	20	+·002	·015
Cenozoic	29	—·008	·021
Intrusive and Effusive	11	—·007	·015
Unclassified	22	+·011	·020
All stations	123	0	·019

The mean with regard to sign for all anomalies is zero, and without regard to sign it is ·019 dyne. The anomalies in the oldest formation have a comparatively large plus mean with the sign considered. Eight of the ten Precambrian stations have plus anomalies. The average size of the anomalies in the oldest formation is much larger than the mean of all. The most recent formation shows a decided minus anomaly with regard to sign. The formations of the intermediate ages have anomalies which are practically normal. The intrusive and effusive anomalies have a mean of —·007 with regard to sign, but the average size is much smaller than the mean of all. The mean of the intrusive anomalies is —·003 and of the effusive is —·011. The number of anomalies in each of these

two formations is so small that no definite conclusions can be safely drawn from them. It is not necessary to consider the unclassified anomalies.

It may appear obvious that this relation between the oldest and newest formations and the anomalies is what should have been expected inasmuch as the densities of the oldest rocks are, on the average, greater and those of the recent rocks lesser than the average surface density, 2·67, used in the computations. But it will appear, on reflection, that after all these cannot be mere surface phenomena.

Let it be assumed that the pressure at the depth of 114 kilometers under a Precambrian station is normal; that is, the crust is in a state of perfect isostasy, and that the average anomaly with regard to sign of +·016 is caused by an excess in density of the geologic formation just under the station. Then if the formation considered extends 1,300 meters out from the station and 1,000 feet below it, this material would have an increase in density of 1·47. With the same radius but with a depth of 5,000 feet, the material would have an increase in density of 0·48. With 10,000 feet, there would be an increase of ·40.

If it is assumed that the formation considered extends 19 kilometers around the station and 1,000 feet down, then an increase in density of 1·37 would be necessary to cause an anomaly of +·016. With a depth of 10,000 feet, the increase would be ·13.

The maximum anomaly in the Precambrian formation is +·054 dyne, therefore the increases in density above the normal would be three and one-half times those previously stated. If this formation is assumed to extend 19 kilometers from the station and to a depth of 10,000 feet, the increase in density would have to be ·45 greater than the normal.

The mean with regard to sign of the anomalies in the Cenozoic formation is −·008, and the changes in density necessary to cause this anomaly are one-half the size and of the opposite sign of the changes necessary to cause the mean Precambrian anomaly with regard to sign of +·016. The maximum anomaly in the Cenozoic is −·091, and to cause this a decrease in density of ·80 is necessary in the material extending 19 kilometers from the station and to a depth of 10,000 feet.

Now let it be assumed that there is normal pressure under a station at the depth of 114 kilometers, and the density of the surface geology is also normal, and that an anomaly is caused by an excess of density in a stratum of material 5,000 feet in thickness, 10,000 feet below the station, which extends horizontally 19 kilometers from the station. Under these conditions an increase of ·32 in the normal density would be necessary to cause an anomaly of +·016.

It is seen that, under the assumptions stated, large changes in the normal densities are necessary, even in thick strata, to account for anomalies of average size. On the other hand, only small changes in density are necessary if it is assumed that the anomalies are caused by a departure from the state of perfect isostasy in the earth's crust. An anomaly of $+\cdot016$ would be caused by a change of $\cdot02$ from normal density in the material of a column 19 kilometers in radius and 120 kilometers in depth. The largest anomaly, $\cdot091$, would be caused by a change in density of only $\cdot12$.

If a column with a radius of 167 kilometers and depth of 114 kilometers be considered, then an increase in density of only $\cdot005$ is necessary to produce an anomaly of $+\cdot016$ and a decrease of only $\cdot03$ in normal density is necessary to cause the Seattle anomaly of $-\cdot091$.

In the same sized column the average Cenozoic anomaly with regard to sign, $+\cdot008$, would be caused by a decrease in density of only $\cdot002$.

It appears to be improbable that the average sized anomalies found in certain geologic formations are the result of greater or smaller densities of the surface materials than that used in the reductions, nor is it likely that the cause is an abnormal density in a stratum of moderate thickness in the upper portion of the crust. Such changes in density no doubt have some effect in causing the anomalies, but it appears to be probable that the principal cause of all except the smaller anomalies is an actual departure from the condition of perfect isostasy in the crust of the earth in the vicinity of the station.

It is extremely interesting that the gravity anomalies, though very small, show a relation to the geologic formation at the earth's surface.

Coast and Geodetic Survey,
Washington, D. C.

Art. XXII.—*An Association of Native Gold with Sillimanite*; by Thomas Leonard Watson.

About a year ago Doctor Craig R. Arnold of Dahlonega, Georgia, kindly sent me a very interesting specimen of pegmatite partly incased in mica schist, which contained in places abundant large and small flakes of elementary gold readily visible to the unaided eye. A thin section was cut from the most favorable free gold-bearing portion of the rock for microscopic study of the relations of the gold to the silicate minerals. In view of the numerous published statements in recent years on the occurrence of primary gold in igneous and metamorphic rocks,* I consider the Georgia occurrence, regardless of mineral associations, to be of some interest as illustrating, microscopically, the subsequent formation of the gold in the rock, which from its observed relations by the naked eye might readily be inferred to have formed contemporaneously with the rock minerals.†

A personal communication from Doctor Arnold informs me that the locality from which the specimen came is on Coosa Creek, some four or five miles south of Blairsville, Union County, Georgia. Although located in the Coosa Creek gold belt, where gold mining has been engaged in from time to time for many years, the several State Survey reports on gold contain no geologic information on the area beyond the mere statement that the rocks are schists or gneisses. There has been some development work in the nature of inclines relative to water level at the locality from which the specimen was taken, but, so far as I am aware, practically nothing is known of the field relations.

The specimen is fresh and apparently represents mostly vein matter, partly wrapped in a thin veneer of mica schist. Quartz greatly predominates, but some feldspar is observed, and this portion of the specimen has the appearance of a pegmatite of irregular but moderately coarse crystallization of the two minerals with some mica. The schist portion of the specimen is a mixture of large shreds and scales of biotite and muscovite through which are distributed somewhat numerous rose-colored crystals of garnet. That portion of the specimen showing much visible elementary gold from which the thin section was cut, corresponds more nearly to the schist although

* See Lincoln, F. C., Certain Natural Associations of Gold, Econ. Geology, vol. vi, pp. 247–302, 1911. Lincoln cites references to the literature.

† This statement refers to the enclosing rock and not to the pegmatite, for it is believed the gold was probably introduced with the pegmatite and therefore contemporaneous in crystallization with its chief minerals, quartz and feldspar.

the appearance is that of gradation from pegmatite into schist, while in other portions the two rock phases are rather sharply differentiated from each other.

In the hand specimen abundant large and small flecks of native gold are noted in intimate association with biotite, the light-colored minerals, and garnet, suggesting in the latter mineral partial rimming and filling of minute fractures or rifts.

Under the microscope the thin section shows intergrowths of biotite and muscovite, quartz, sillimanite, orthoclase and plagioclase feldspar, garnet, occasional pyrite, and several unimportant microscopic accessory minerals. Biotite is partly altered to chlorite, is dark brown in color, has strong absorption, and contains numerous inclusions of zircon surrounded by characteristic dark borders. Muscovite, in large and small shreds possessing good cleavage and partly intergrown with biotite, is plentiful. Orthoclase is probably in slight excess over plagioclase and both feldspars show intergrowths with quartz in micrographic structure. A considerable portion of the thin section is occupied by an aggregate of sillimanite fibers having partial radiating arrangement, intergrown with biotite, and closely associated with muscovite, the longer axis of the sillimanite fibers crossing at all angles the cleavage direction of muscovite. Much of the sillimanite is colored brown and is pleochroic from fine scales of biotite lying between the sillimanite fibers. The relations of the two minerals suggest possible derivation of sillimanite, in part at least, from biotite, a change which according to Van Hise* may take place under conditions of elevated temperature and pressure. Quartz shows optical disturbance and contains liquid and solid inclusions. Garnet is without crystal boundaries and exhibits rifts or minute fractures. Pyrite is only sparingly present but appears entirely fresh.

That portion of the specimen from which the thin section was cut shows unusual richness in native gold, the particles of which range from tiny granules up to irregular grains 2^{mm} or more in diameter. The gold occurs associated with all the principal minerals including sillimanite and garnet, and is in juxtaposition with several grains of pyrite, partly enclosed by biotite; but in each case the boundaries between the two minerals are sharply defined and the pyrite shows no indication of alteration. It occurs as interstitial grains between the quartz and feldspar and the other minerals, and in some cases is embedded in the substance of the quartz and feldspar, and to a

* Van Hise, C. R., A Treatise on Metamorphism, Mon. No. XLVII, U. S. Geol. Survey, pp. 342–343, 1904. Dr. Van Hise states that biotite rarely alters into hypersthene and sillimanite, and the formation of these from biotite "usually occurs in connection with contact reactions of igneous rocks; . . . ."

limited extent with their micrographic intergrowths. It is interleaved along cleavage directions with both biotite and muscovite, occasionally extending across the cleavage in fractures and sometimes formed along the mineral boundaries, being especially noticeable as partial rims to biotite; between the acicular crystals of sillimanite, sometimes as large and

FIG. 1.

FIG. 1. Photomicrograph showing relation of native gold (in black) to quartz and feldspar (white areas), garnet (light-colored mineral of high relief near center of figure), and biotite the intermediate dark mineral, a large shred of which occupies the lower part of the figure. Gold partially rims and fills fractures in the garnet, and lies along the cleavage positions in the biotite. Magnified 60 diameters.

small irregular areas and sometimes filling distinct fractures in the mineral; and partially rimming and filling microscopic rifts in the garnet.

These diverse relations of the gold to the rock minerals are shown in figures 1 and 2, which are microphotographs of different parts of the thin section. An interesting feature of the rock is the presence of abundant sillimanite and native gold in intimate association, as indicated in fig. 2. Microscopic study discloses the relations of the two minerals to each other to be such as to indicate that the sillimanite formed in advance of the gold. Rifts or microscopic fractures are shown in the sillimanite, garnet, and micas, and the quartz exhibits strain phenomena. Muscovite is not infrequently bent and sheared and sometimes broken across. These structures have developed since the formation of the rock, and since the gold fre-

quently fills them, it is clear that it has been introduced subsequent to the formation of both the original and metamorphic minerals, such as garnet and sillimanite. Some pyrite is present in the rock, and while the gold is closely associated with it in some instances there is no evidence suggesting the derivation of the gold from pyrite by alteration. In the

Fig. 2.

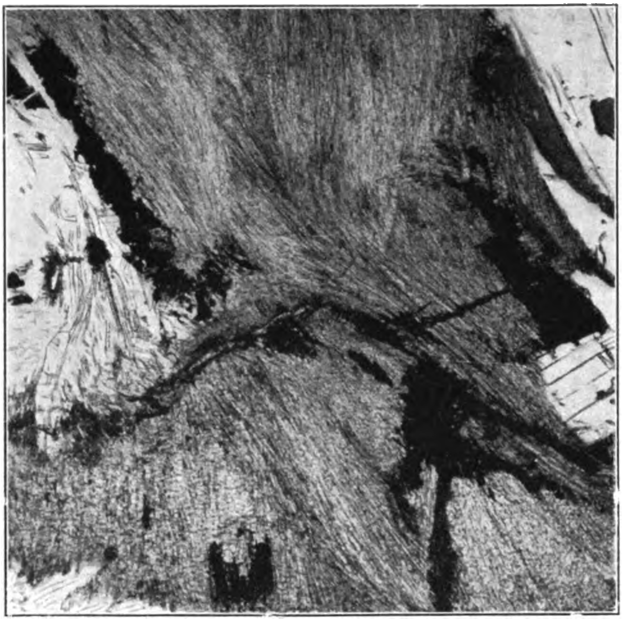

Fig. 2. Photomicograph showing relation of native gold (in black) to sillimanite, the fine fibrous mineral which occupies most of the field. Gold is shown as irregular black areas in the sillimanite partly lying between fibers and partly filling fractures. White mineral occupying marginal positions is muscovite showing some thin foils of gold (black) interleaved along cleavage directions. Intermediate dark mineral is biotite with partial rims of free gold (black). Magnified 60 diameters.

absence of accurate knowledge of the field relations, conclusions based wholly on the single hand specimen and thin section are of doubtful value; but so far as these can be relied on the evidence suggests that the gold was probably introduced into the wall rock•with the pegmatite-making solutions and formed in the relations to the rock minerals as described above and as indicated in the two figures photographed from the thin section.

Brooks Museum, University of Virginia.

ART. XXIII.—*Hecker's Remarks on Ocean Gravity Observations;* by L. A. BAUER.

IT is frequently suggested by persons, presumably familiar with previous work, that it would be desirable to include gravity observations on the *Carnegie*. We are told that ocean gravity work, of requisite accuracy, is one of the few remaining heroic problems. Before deciding on any additional work a careful survey is made of existing knowledge and of the actual requirements for obtaining trustworthy data. I was thus led into an examination of past ocean gravity work, viz., that by Dr. Hecker on three cruises between 1901–09, under the auspices of the International Geodetic Association and published in three monographs aggregating 500 quarto pages. Examination was made at first only in general; however, I soon became engaged in an exhaustive examination of the entire problem, not only going this time more deeply into Hecker's methods of observation and of computation, but also consulting experts in thermometry and barometry of the U. S. Bureau of Standards and of the U. S. Weather Bureau, besides well-known geodesists and physicists. The final result of this preparatory study was the paper "On Gravity Determinations at Sea" published in this Journal, January, 1911. This paper received the endorsement of several well-known investigators to whom the manuscript was submitted before publication. Its special aim was to arouse general interest in this difficult subject and to assist in making clear the direction in which further advance was necessary. Returning December 24 from a cruise of the *Carnegie*, I found that Dr. Hecker had made reply to some points in my paper. His remarks were originally published in the journal of which he is chief editor (Gerland's Beiträge zur Geophysik, Bd. xi, Heft 1, June, 1911, p. 200); in November a modified translation appeared in this Journal. References throughout this article will be to this translation.

I must begin by correcting some of Hecker's statements. He infers that we have introduced for gravity work on the *Carnegie* an inferior method of reading the boiling-point thermometer, viz., with a hand lens instead of a telescope, as he had done. I had stated explicitly (*l. c.*, p. 4) that the boiling-point observations on the *Carnegie* were not made for the purpose of gravity determinations; "the prime purpose being to obtain data for controlling the corrections of our aneroids, the instrumental equipment was in accordance with this aim." This was on our first cruise; on the present cruise we have replaced the hand lens by a telescope, but we are not yet willing to regard our individual results as gravity determinations.

The experts consulted agreed that it would not be safe to rely exclusively upon barometers, as did Hecker, damped to such a degree that, as he confesses, observations made with them at sea, under supposedly ideal conditions, were not of the desired accuracy. Thus he says (*l. c.*, p. 390), "this, of course, cannot be otherwise, for, as is well known, highly damped barometers, when perfectly at rest, do not have very accurate readings." As the final outcome of all conferences and experiences, the conclusion has been reached that it will not be worth while to take up gravity work seriously on the *Carnegie* unless substantial improvements can be made upon the boiling-point–barometer method; we are continuing, however, with our present equipment, the necessary observations for the control of our aneroids. I shall have to postpone for some future occasion the report upon this feature of our work.*

In spite of all care bestowed, the possibilities of appreciable errors are so numerous as to raise the question whether gravity data obtained by Hecker's method would yield individual results of requisite accuracy. These errors in themselves appear trivial until converted into gravitational quantities. Thus, for example, an error in the boiling-point temperature of but $0°{\cdot}001$ C. corresponds to about $0{\cdot}035^{cm}$ or 1/28000 part of g, the order of accuracy required, I am informed, to meet modern requirements. It may be that Hecker considers that he has reached this accuracy. As the result of my examination I was led to the conclusion (*l. c.*, p. 161) that "it will not be surprising if it be found that many of the most recently published results are in error by an amount approximating to $0{\cdot}1^{cm}$, or about 1/10000 part of g."

Hecker questions my statement regarding his thermometer corrections. The facts as derived from his three publications are as follows (pp. 6–7, 1903; pp. 81–83, 1906, and pp. 39–40, 1910). The *total* corrections of thermometers employed in the Atlantic cruise of 1901, the Indian and Pacific Ocean cruise of 1904–05, and in the Black Sea work of 1909, were determined but once, viz., before starting out in 1901. If I understand him rightly, only the corrections dependent upon inequalities of bore of tube (the calibration corrections) were determined a second time, namely, at the end of the work in 1904–5. All other corrections, however, *e. g.*, those dependent upon the zero, the fundamental interval, reduction to standard scale, etc ,

* Hecker is correct with regard to the impossibility of reading successive high and low phases of the barometers used on the *Carnegie*; I had misinterpreted the observer's notes. However, since then we have made some preliminary experiments in which successive high and low readings were obtained by using a hand magnifier and estimating the readings, as closely as possible, with the eye and attempting to secure the requisite accuracy by multiplying the observations under varied conditions on the principle successfully used in our magnetic work.

were ascertained only once. Thus the comparison of Hecker's thermometers with the standard of the Physikalische Reichsanstalt, or with any other standard, were never again repeated as far as known. Hecker does not give the actual observed corrections, but, instead, a table computed therefrom, which, except for very slight corrections due to the second determination of the calibration corrections, is used for the three cruises. Hecker assumed that the variations in the mentioned corrections, with age and use of thermometers, would either be negligible or "give only a constant difference," and hence enter into the miscellaneous constant term of his observation equation. How justifiable these assumptions are I leave others to judge. Due to the severe conditions imposed by his strenuous program, Hecker had serious trouble at times with his thermometers—sufficient, indeed, to require rejection of some series. The caliber corrections, I am informed by thermometry experts, are the ones least liable to appreciable changes, and from their re-determination no certain conclusions can be drawn as to the behavior of the other and more important corrections.

Since Hecker criticises our proposal as to the necessity of frequent controls of the zero point, it will be of interest to quote from such an eminent authority on precise thermometry as Professor Callendar: "The effect [of zero changes] cannot be calculated or predicted in any series of observations because it depends in so complicated a manner on the past history and on the time. It is a most serious difficulty in accurate mercurial thermometry, especially at high temperatures. The most satisfactory method of correction appears to be to observe the zero *immediately after each reading* and to reckon the temperature from the variable zero thus observed." The various experts consulted in this country are in entire accord with Professor Callendar. Now this is what Hecker says (*l. c.*, p. 392): "The reason why I made no freezing-point observations is that they would have introduced new errors into the observations; for freezing-point observations are also subject to errors." Experienced physicists would say that the neglect of the zero control introduced greater uncertainty than that of a zero determination. Hecker depended too much upon the possibility of eliminating all outstanding evils by general least square adjustments; this same remark applies to other matters referred to in his comments, *e. g.*, barometer corrections.

A word with regard to Hecker's least square treatment of his observational quantities. While I have pointed out wherein his observational work was in some respects not wholly satisfactory, I am inclined to think that the error due to reduction will be found to be greater than the purely observational one.

I have shown (*l. c.*, p. 10) that his unknown quantities "are not strictly instrumental or ship constants, but depend upon the area (extent and geographic position) from which they are derived." Hecker does not appreciate that they can hence only be used within the area embraced by the stations entering into his adjustments and not outside, for extrapolation purposes. For example, in his 1910 revision Hecker assumes that the unknowns derived from selected stations between the Tongas and San Francisco likewise hold for the disturbed region, Sydney to the Tongas. The 1910 computation increases the gravity anomalies between Sydney and Tonga at times by $0{\cdot}1^{cm}$ and more over those of 1908; the largest gravity anomaly of all his cruises, $+0{\cdot}393^{cm}$, is now placed in this region, viz., off the north extremity of New Zealand. The 1908 computation, on the other hand, gave as the largest anomaly, $+0{\cdot}319^{cm}$, off Honolulu. The Sydney-Tonga region is that for which Hecker appeals to Kohlschütter's paper in confirmation of his work. Kohlschütter's own observations were not made on the ocean but on land, in German East Africa. His general conclusion would doubtless hold as well for Hecker's 1908 results as for those of 1910.

Omitting the rejected port observations, it is found for the Atlantic work that 44 out of 47 available results were utilized, whereas for the Indian and Pacific Ocean cruise, out of 136 collected results 65 enter into the least square adjustments for the derivation of the required unknowns. Those who must utilize Hecker's anomalies should bear in mind the extent to which they are already subject to the law of accidental distribution assumed in the adjustments. It may also be of interest to record here, that for 85 per cent of the total work the application of correction due to course and speed of vessel and the rejection of the port results has increased the sums of the gravity anomalies squared, the increase being most pronounced where extrapolated coefficients have been used.

Hecker has overlooked the salient feature of our proposed plan, viz., the prime importance of so arranging observational work as to admit of but one logical method of reduction, and the necessity of restricting the unknowns to a few physically determinable ones. I hope that I shall not be regarded as unappreciative of his labors. In fact, only one who is himself engaged in ocean observational work can adequately realize the countless difficulties which had to be overcome. My chief aim has been to assist in setting before those who use his results their precise limitations.

Washington, D. C., January 22, 1912.

Art. XXIV.—*Relations of the Degree of Metamorphism to Geological Structure and to Acid Igneous Intrusion in the Narragansett Basin, Rhode Island;** by F. H. Lahee.

Part I.

Contents.

Acknowledgments.

For the use of laboratory equipment and for valuable advice in the preparation of the original thesis, the writer wishes to express his gratitude to Professor J. E. Wolff and Professor J. B. Woodworth, under whose direction the work was carried on; and for numerous suggestions and favors, to Professors W. M. Davis, A. Sauveur, and C. Palache; to Dr. Ernest Howe; and to Messrs. R. W. Sayles, J. A. S. Monks, Wm. Burns, and W. P. Haynes.

Introduction.

The Narragansett Basin is a body of Carboniferous strata, fifty miles long, from fourteen to twenty-five miles wide, and with a total stratigraphic thickness of somewhat more than two miles.† From the southern coast of eastern Rhode Island it trends northward as far as a line between Fall River and Providence, including the major part of Narragansett Bay within its boundaries, and thence, bending more to the east, extends in a northeasterly direction to near Hanover, Massachusetts.

Topographically the Basin is represented by a shallow depression with an uneven surface, between bordering

* The present paper is an abstract of a thesis accepted for the degree of Doctor of Philosophy in Geology, at Harvard University, in June, 1911.

† Shaler, N. S., Foerste, A. F., and Woodworth, J. B., Geology of the Narragansett Basin. U. S. G. S., Monog. XXXIII. 1899. See pp. 208–210, 336, 338, 345, 358, and 373, and Plate xxx.

FIG. 1.

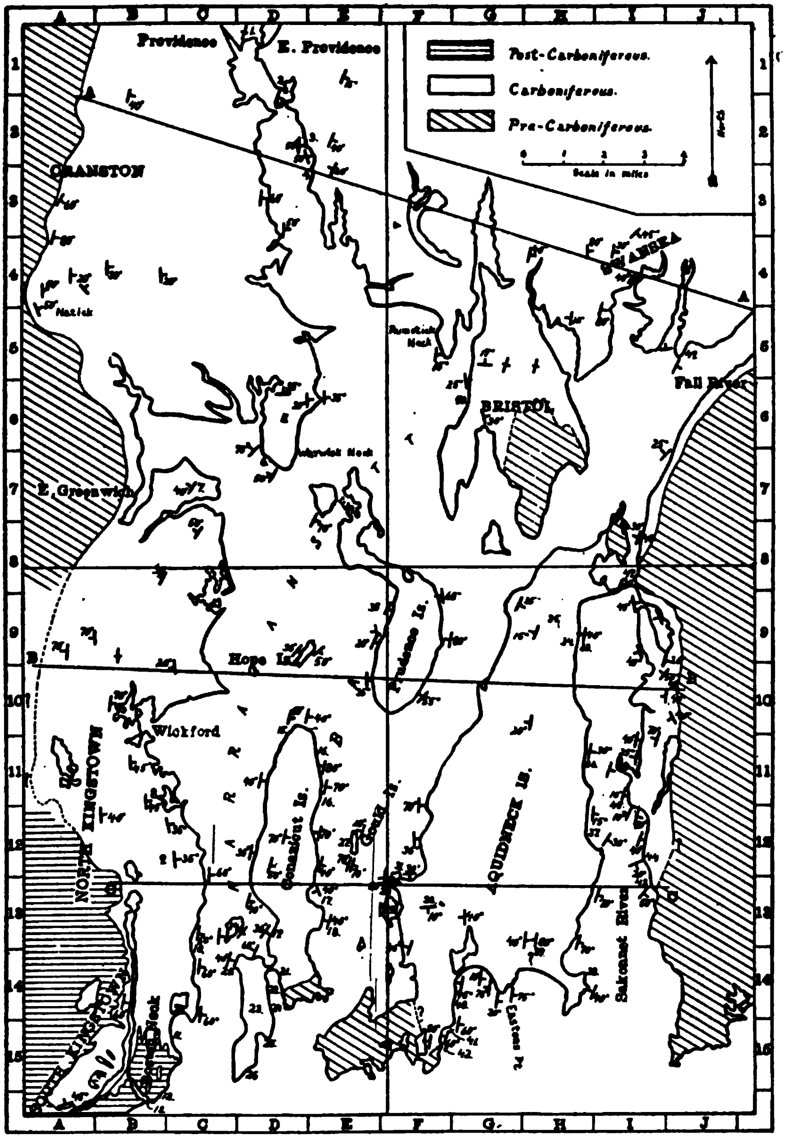

FIG. 1. Outline map of the southern half of the Narragansett Basin. Many of the dips and strikes are somewhat generalized. References to numbered localities will be found in the text.

ridges of harder rocks. A few inliers of the harder rocks occur surrounded by the Carboniferous (see fig. 1). On all sides, except in the broken southern rim, the same statements hold true, namely, that the predominating border rocks are granites or granite gneisses and that these granites are intrusive into sedimentary formations, now much metamorphosed. The granites (Sterling granite series) in South Kingstown are probably post-Carboniferous and the schists enclosed in them, Carboniferous;* but elsewhere the plutonics are pre-Carboniferous, as is proved by the presence of their disintegrated débris in the Carboniferous.

The strata of the Basin are shales, sandstones, arkoses, and conglomerates, which have been folded, metamorphosed, and injected by an acid series of dikes and veins, offshoots from the post-Carboniferous granites of Kingstown. The anticlines are relatively long and narrow, after the Appalachian pattern, and crumpling of minor dimensions often occurs superposed upon the major folds. Although there are innumerable exceptions, the metamorphism, regarded from a broad standpoint, is distinctly greater in the southern part of the field than in the northern. The acid intrusives range in composition from highly feldspathic pegmatites to veins of pure massive quartz. Moreover, they are much larger, and there are many more of them, in South Kingstown than farther northward and eastward.

Throughout the Basin, then, the texture and composition of the sedimentary rocks, the complexity of the folding, the degree of metamorphism, and the composition and abundance of the acid dikes, are variable factors. It has been our aim to investigate the kinds and degrees of metamorphism and to correlate them with the other variable factors just mentioned, with stratigraphic depth, and with geographic position in the Basin. The greater portion of the work has been carried on in the southern half of the field, where the exposures are more satisfactory.

The first part of this paper will treat of the Structural Geology of the Carboniferous rocks; the second, of the Petrology and Metamorphism of the Carboniferous rocks; and the third, of the post-Carboniferous intrusives. There is no need of describing the pre-Carboniferous rocks in detail. Their importance for us rests (1) upon their having constituted the floor upon which the Basin sediments were laid down, and (2) upon their relations to the forces which deformed these sediments; and these matters will be taken up under the other heads.

The remark is perhaps unnecessary that no attempt could be made to obtain exact quantitative results, because the relations

* Loughlin, G. F., Intrusive Granites and Associated Metamorphic Sediments in Southwestern Rhode Island, this Journal, xxix, p. 447, 1910.

between such factors as mineral composition and intensity of deformation, or degree of deformation and stratigraphic depth, and the like, obviously cannot be measured with precision. Yet a broad, general quantitative dependence can be determined.

Structural Geology of the Carboniferous Formation.

Theoretical Considerations.—Before describing the structural geology of the basin, let us see what variations in intensity of folding may be expected, on theoretical grounds, in a region of deformed strata.

A fold, in the geological sense, is the expression of variable

Fig. 2.

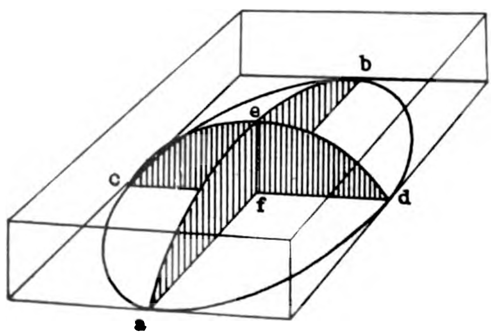

Fig. 2. Diagram of an elliptical quaquaversal anticline. *a-e-b-f*, axial plane.

a-b, direction of operation of minimum component of force.
c-d, direction of operation of maximum component of force.

compressural forces which have operated upon variable resistances. In most cases the pressure has been applied along approximately horizontal lines. However numerous the forces may have been, they may be regarded as having been equivalent to two components,—one of maximum value, which acted parallel to the greatest compression, and one of minimum value, which acted parallel to the least compression, at right angles to the first.

The simplest illustration is the quaquaversal anticline (see fig. 2). Here *a–b* is the direction of the minimum component, and *c–d* is that of the maximum component. Pitch, measured along the slopes *e–a* and *e–b*, is really dip in the axial plane, *a–e–b–f*. Whenever there is a pitch—and it may be stated as a

rule that pitch is practically universal in regions of folding*—the deforming forces were variable in direction and they may be considered as resolvable into two components as above explained. The ratio between these components will then be indicated by the ratio between the degrees of compression perpendicular to, and parallel to, the axis of the given fold.

According to Van Hise,† folding may be *parallel* or *similar*. In parallel folding the contacts between adjacent beds

FIG. 3.

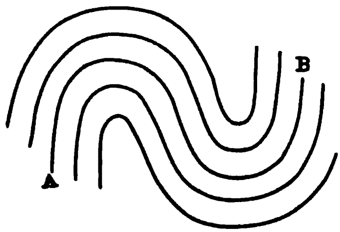

FIG. 4.

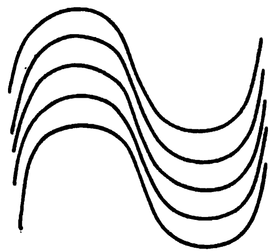

FIG. 3. Parallel folding. A-B, fundamental curve.
FIG. 4. Similar folding.

are parallel to one another and the thickness of any bed is essentially uniform throughout (see fig. 3). On the other hand, in similar folding the contacts between adjacent beds are identical in size and shape and the thickness of every stratum is considerably greater in the axial regions than on the limbs‡ (see fig. 4). Again, in parallel folding that curve in which all anticlines and synclines are of equal size and shape may be termed *fundamental* to the structure (A–B, fig. 3). Above the fundamental curve synclines narrow and become 'pinched' or 'carinate', and below it anticlines undergo the same alteration in form. Obviously no such discrimination is possible in similar folding. It may be shown that, while deformation is in process, differential movement (shearing) near the fundamental curve is at a maximum in the limbs and at a minimum in the crests and troughs; but that, away from this curve, both upward and downward, the locus of maximum differential movement migrates from the limbs to the axial regions,

* See, for example, the following: Reade, T. M., The Origin of Mountain Ranges, xxx, p. 178. London, 1886. Reade, T. M., The Evolution of Earth Structure with a Theory of Geomorphic Changes, p. 195. London, 1903. Shaler, N. S., etc., op. cit., p. 32. Van Hise, C. R., Deformation of Rocks, Jour. Geol., iv, pp. 312, 344, 348–349. 1896.

† Van Hise, C. R., Principles of North American pre-Cambrian Geology. U. S. G. S., Ann. Rept. XVI, Pt. I, 1894–1895, pp. 598, 599. Also, by the same author, Deformation of Rocks, Jour. Geol., iv, pp. 210, 211, 1896.

‡ Van Hise, C. R., Principles of North American pre-Cambrian Geology, pp. 598–601. Also, Heim, A., Untersuchungen über den Mechanismus der Gebirgsbildung, Basel, 1878, p. 48.

reaching these where the folds are most acutely pinched. In similar folding maximum shearing is always in the limbs.*

If strata, deformed after the parallel pattern, have a pitch, carinate anticlines become flat and flat synclines become carinate, when traced in the direction of pitch; but in similar folding, since dips are always steeper on the limbs than on the axes, no amount of pitch can alter these relations. Parallel folding, representing less readjustment of beds than similar folding, is more common and is generally on a larger scale than the latter. It must be remembered that these statements apply to mathematical ideals only, and that, under natural conditions, there is considerable variation. The two types are not always sharply distinguished; yet there is sufficient approximation to the ideal to make the classification valuable.

Given a force in operation, a more rigid body will oppose deformation by this force more successfully than a less rigid body. If adjacent rocks of different degrees of rigidity are under lateral compression, whether the forces be regarded as acting parallel or perpendicular to the contact surfaces between the rock masses, there is a tendency for transmission of these forces by the stronger body.† The first condition—of force parallel to contact, i.e., about parallel to the beds—is that for the development of *competent structure*;‡ the second condition—of force about perpendicular to contact—is illustrated by the relations between hard crystalline border-rocks and less resistant basin sediments, after deformation of the original land surface has progressed far enough. In nature the differences of rigidity are practically never so great that one rock merely transmits the force while the other accomplishes all the accommodation. Both usually suffer, but one less than the other.

The more rigid a rock mass under compressive strain, the farther from the point of application of the force will the effects of that force appear. For this reason, unless a stratum has competency sufficient to enable it to span the breadth of the deformed belt, the folds are apt to be closer and more numerous near the point of application and to die out away from it;§ and the less the rigidity of such a stratum, the more rapidly will the folds subside.

* Van Hise, C. R., "Principles", etc., p. 598.

† Harker, A., On Slaty Cleavage . . . , Rept. Brit. Assoc. Adv. Sci., 1885, p. 848. Heim, A.: Op. cit., p. 40.
Van Hise, C. R., Deformation of Rocks, Jour. Geol., iv, pp. 204, 472, 1896.

‡ Willis, B., The Mechanics of Appalachian Structure, U. S. G. S., Ann. Rept. XIII, Pt. II, 1891–1892, p. 247.

§ Shaler, N. S., etc., op. cit., p. 16.

According to the foregoing review of theoretical facts, variations in the intensity of deformation may be due (1) to the type of folding; (2) to the position of the outcrop in the fold; (3) to the degree of rigidity of the rock: and, (4) to the distance of the outcrop from the point of application of the force. Provided the proper conditions prevail, then, we should expect to find such variations in the structure of the Narragansett Basin.

In the description which is to follow, we shall be able neither to mention strikes and dips of individual outcrops * nor to debate the pros and cons of questionable intepretations of the folding.† The method of procedure will be indicated and then the facts will be presented in summary form.

The Borders of the Basin.—As may be seen on the map, the borders of the Basin have many irregularities of trend. Causes for these changes in direction may be: (1) a pre-Carboniferous hill-and-valley topography, forming the floor of the Basin; (2) the deformation of a more level pre-Carboniferous land surface; or, (3) a system of post-Carboniferous faults. If the first supposition were true, the Carboniferous sediments should often abut against the pre-Carboniferous, and there should be little dependency between strikes of the strata and strikes of the surface of unconformity separating the Carboniferous and the pre-Carboniferous. But such is not the case. There is a remarkably close parallelism between the attitude of this surface of unconformity and the attitudes of the adjacent Basin sediments. Indeed, it is just what would be expected if the Bason floor had been originally comparatively flat and had later shared in the diastrophism of the overlying strata. Further evidence for deformation of the basement, according to Shaler, is to be seen in a certain amount of schistose structure in the eastern and western border-rocks, which decreases in intensity away from the Basin.‡

The Basin floor has been deformed not only by bending, but also by faulting. This is indicated locally by exceptional straightness of the rim, by apparent displacement of beds or of groups of beds, and by zones of fault brecciation. Whether all of this fracturing is of the normal, or tension, type, or whether some of it is of the reversed, or compression, type, could not be determined. Certainly many of the faults are normal.

Summarizing, we infer (1) that the original floor of the Basin, which comes to the present topographic level in or near

* The strikes and dips have been more or less generalized for different localities and have been plotted on the map (fig. 1).

† For these see Shaler, N. S., etc., op. cit., and Lahee, F. H., A study of Metamorphism in the Carboniferous Formation of the Narragansett Basin; thesis deposited in Gore Hall, Harvard University, in 1911.

‡ Shaler, N. S., op. cit., pp. 19–20.

the pre-Carboniferous borders, had a relatively flat, or at most a gently undulating, surface; and (2) that this surface underwent deformation, both by folding and by faulting, in company with the superjacent strata.

THE BASIN STRATA.—In drawing conclusions with respect to the structural relations of the Carboniferous strata, considerable latitude of interpretation is inevitable. Among other reasons this is partly because plant remains, although common, have not yet been proved to be of value in this region as indices of stratigraphic horizon, and furthermore, because the entire series of shales, sandstones, and conglomerates, of the Basin, while characterized by numerous textural variations, is so similar throughout that mineral composition and lithologic structure are almost worthless for correlation. In general, however, a broad sequence has been made out, passing upward from basal conglomerates and arkoses (Pondville arkose, Natick conglomerate, etc.), through a great thickness of conglomerates, sandstones, and shales with some coal seams (Kingstown and Aquidneck series), to an overlying coarse conglomerate (Dighton and Purgatory conglomerates).

The deformation of these sediments has produced folds of various sizes and shapes. We shall make a distinction between *major* folds, which are sufficiently large and important to be represented in an ordinary generalized vertical section, and *minor* folds, which would usually be omitted from such a section. By *contortion* we mean complex minor deformation in which the strata are bent into closed or overturned folds, or are otherwise severely compressed. Upon this arbitrary classification we shall base the succeeding description.

Major folding.—Evidences for variations in the major folds may be observed in such factors as the direction of strike, the degree of dip, the direction and amount of dip of axial planes, and the direction and amount of pitch, if there is a pitch.

Strikes—The greatest regularity of strikes (between 5° and 20° E. of N.) occurs in the Kingstown formation, (1) in the western coast belt—between the western border and the western coast of Narragansett Bay—on Boston Neck (B:15)* and northward to Barber's Height (B:12), and (2) in northern Conanicut Island (D:10–13). That is to say, great uniformity is found only in the southwestern portion of the Basin where dips, as a rule, are rather steep. Such parallelism signifies that the maximum component of force was here practically supreme.

Somewhat less uniformity of direction is shown between Hamilton (Loc. 8, B:11) and East Greenwich in the western coast belt, and also on Prudence Island.

* The map (fig. 1) is coördinated by letters and figures along the margins. Some localities are numbered. These will be indicated as follows in the text: Loc. 10, C:13, i. e., Locality 10 in coördinate square, C:13.

Districts in which the strikes are conspicuously variable are as follows: Northwest of Watchemoket Cove (D:1), Ponham Rock-Riverside area (D and E:2), southeastern Cranston (A:4), Warwick Neck, Bristol Neck, Hope Island, Potter's Cove on Conanicut Island (Loc. 17, E:13), eastern coast of Mackerel Cove (Loc. 21, D:14), Beaver Tail Peninsula (Loc. 23, D:14), Coaster's Harbor Island (Loc. 29, F:13), Sheep Point district (Loc. 42, F:15), area north and northeast of Warren Neck (H and I:3 and 4), Brayton Point (Loc. 49, J:5), and the eastern coast belt.

Strikes of the western coast belt, then, are fairly regular, although with some rather abrupt changes in direction. On the contrary, strikes of the eastern border region are very irregular and, except along the coast north of Stone Bridge (Loc. 47, I:8), have no particular relation to the eastern edge of the Basin. The lack of system here is probably due in part to faulting.

Dips.—Without entering into detail, we may say that steep dips predominate in the southern portion of the area, and low dips in the northern. Many of the actual readings are recorded on the map.

Pitch.—A definite northward pitch is indicated in the following places: Warwick Neck, Rumstick Neck, Hope Island, southeast coast of Prudence Island, Gould Island, southern Swansea, and High Hill Point (Loc. 45, I:11–12). Southward pitch was recorded near Silver Spring (Loc. 3, D–E:2), half a mile northeast of Riverside (E:2), northeastern coast of Prudence Island, north side of Butt's Hill (near Loc. 35, H:9), one mile west of Portsmouth Village (H:9), Coddington Cove (Loc. 31, F:12–13), Beacon Hill (Loc. 32, F:13), probably north of the Paradise tract (H:14), and at Easton's Point.

Pitch is more commonly low than high. In general, it is high where adjacent strikes and dips are variable (Swansea, Coddington Cove, Warwick Neck), or where adjacent dips are steep (Gould Island); and it is low in the broad folds (Prudence Island, Easton's Point); but there are exceptions.

*Axial planes.**—Axial planes are vertical or dip either eastward or westward without regard to whether the fold is nearer the eastern or western border of the Basin. That is to say, with reference to these border regions as comparatively rigid beams through which the forces were applied against the sediments, both overthrusting and underthrusting were produced.

Continuity of the major folds.—Because of these variations in strike, dip, pitch, and symmetry, and especially because of the wide water intervals between the land areas, the identity of separate folds can rarely be discerned across many miles.

* See generalized sections, figs. 5 to 7.

Almost without exception, however, the axes of the major folds trend a little east of north, thus proving that the maximum deforming forces acted along approximately east-west lines.

Relative number of folds across the Basin.—East-west sections across the Basin show a varying number of folds in different latitudes. To illustrate this fact, sections along lines A-A, B-B, and C-C (fig. 1) have been drawn, as nearly as possible perpendicular to the strike (see figs. 5 to 7). By dividing the number of major folds (both anticlines and synclines) inter-

Figs. 5, 6, 7.

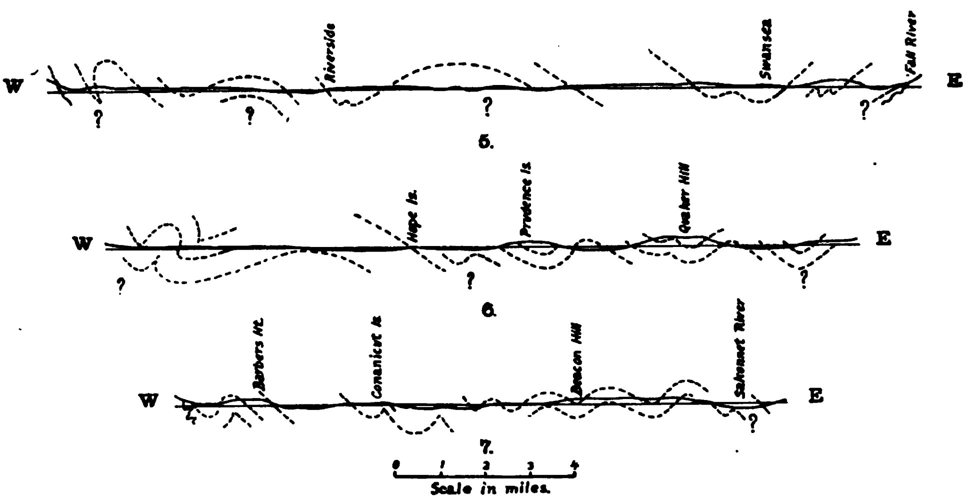

Fig. 5. Generalized vertical section along the line A-A in fig. 1.
Fig. 6. Generalized vertical section along the line B-B in fig. 1.
Fig. 7. Generalized vertical section along the line C-C in fig. 1.

sected by any line by the length of this line, we may estimate the number of folds per unit of length of the given line, that is, per unit of width of the Basin where the line is situated. In each case land and water areas are traversed. Since the determination of the folding is founded upon data obtained on land, we have calculated the results not only upon the total lengths of the lines, but also upon the sums of their land portions. An important source of error lies in the method of interpreting the geological structure, and the opportunity for mistake is greater in the north than in the south. To offset such error we have chosen, in each case, that interpretation which assumes the greatest reasonable number of folds. For example, in the Cranston area, where the structure has been explained by some as monoclinal and by others as consisting of

two synclines and an anticline, we have adopted the latter hypothesis. Following are the results:

Line.	Fold traversed.	Length of line in miles.	Number of folds per ten miles.	Sum of land portions in miles.	Number of folds per ten miles of land breadth.
A.	9	19	4·73	16	5·62
B.	13	16	8·12	8·75	14·85
C.	16	13·5	11·85	9	17·78

This table indicates that the number of principal folds per unit of Basin width, and, therefore, the degree of compression, regularly increases southward.

Minor folding.—Contortion of the strata was recorded at the localities listed below:

Number of locality*	Location on map	Type of rock
1.	D : 1	Shale, sandstone, little conglomerate†
4.	D–E : 2–3	Chiefly sandstone and shale
5.	D : 6	Shale
6.	D : 7	Shale and sandstone
7.	C : 7	Shale and fine sandstone
10.	C : 13–14	Shale and sandstone
11.	C : 15	Shale and sandstone
12.	B : 16	Shale and sandstone (inclusions)
13.	B : 16	Shale and sandstone (inclusions)
14.	C–D : 13	Chiefly shale and sandstone
15.	D : 10–11	Chiefly shale
16.	E : 11	Chiefly shale
18.	E : 13	Shale
19.	D : 13	Shale
20.	C–D : 14	Shale and sandstone
21.	D : 14	Shale
22.	D : 14	Shale
25.	D : 15	Shale
26.	D : 15	Shale
27.	E : 12	Chiefly shale
28.	E–F : 13	Shale and arkose
29.	F : 13	Shale, sandstone, and conglomerate
30.	F : 12–13	Shale and sandstone
33.	H : 9	Chiefly shale
36.	H : 11	Chiefly shale
37.	H : 12	Chiefly shale
38.	H : 14	Shale and arkose
40.	G : 14	Shale, sandstone, and conglomerate
41.	F–G : 15	Shale
44.	I : 12	Chiefly finer rocks
46.	J : 10	Chiefly sandstone and conglomerate
48.	I : 8	Shale, sandstone, and conglomerate
49.	J : 5	Shale and fine sandstone
50.	G : 6	Shale and sandstone

* These numbers are plotted on the map.

† For convenience the rocks are here spoken of as shales, sandstones, or conglomerates, whether or not they have been metamorphosed.

Localities 4, 16, 27, and 33 are near the axial regions of major folds (all pinched anticlines); 10, 14, 15, 20, and 48 are on the limbs of major folds; and the others cannot be surely placed in this respect. Evidently, then, there is no hard and fast rule for the location of contortion in the larger folds.

If the map be divided into four equal rectangles (by lines in F and in 8 of the coördinate squares, fig. 1), three of the localities of contortion will be included in the northeastern area; five in the northwestern; eleven in the southeastern; and fifteen in the southwestern. That is, more contortion is found southward and westward in the Basin.*

In five of the localities the contortion affects shale, sandstone, and conglomerate, or sandstone and conglomerate; in twenty-nine it affects shale and sandstone—usually fine—or shale alone. According to this, contortion is limited chiefly to the clastics of finer texture (see p. 254).

Areal distribution of variations in the major and minor folding.—Taking into consideration both dip and strike of major and minor folding, we could show that, if we should pass across certain regions in the Basin, the complexity of the deformation would increase. Thus, there is evidence for an increase in the complexity of folding,

(1) westward, in East Providence (D–E: 1–2);
(2) eastward and westward from the middle of the western coast belt, north of East Greenwich;
(3) southward, in Warwick Neck;
(4) westward, in the western coast belt, between East Greenwich and Wickford;
(5) southward, in the western coast belt, south of East Greenwich;
(6) eastward, in Prudence Island;
(7) westward, from Prudence Island to Hope Island;
(8) eastward, in northern Conanicut Island;
(9) westward, from southern Conanicut Island to the western coast belt;
(10) southward, on Aquidneck Island;
(11) eastward, in northern Aquidneck Island;
(12) eastward, from Aquidneck Island to the eastern coast belt;
(13) westward, from middle Aquidneck Island to eastern Prudence Island, Coddington Point, and Coaster's Harbor Island; and
(14) southward, in Swansea.

Obviously there is not uniform increase in complexity from

* This relation is not due essentially to a greater number of outcrops in the southern district.

the middle of the Basin to the walls. Such an increase does occur, however, within three or four miles of the borders, a phenomenon which might be explained by the greater proximity of these rocks to the pre-Carboniferous mass which transmitted, probably in part, the deforming thrust.

Apparently there are alternating, nearly north-south belts of greater or less intensity, belts which cannot usually be traced continuously. These belts are as follows: (1) along the western border; (2) Warwick Neck, northern Narragansett Bay, and Providence River in the latitude of East Providence, and the city of Providence; (3) eastern part of northern Conanicut Island; (4) Gould Island, Coaster's Harbor Island, Coddington Point, and eastern Prudence Island; and, (5) Sakonnet River, and eastern coast belt.

These facts refer to variations along east-west lines. As for north-south directions, only southward intensification of the deformation was noted, and this was in Swansea and, in general, from the latitude of Prudence Island.

Conclusions.—From the preceding statements certain inferences may be drawn.

(1.) The high dips of Carboniferous strata resting unconformably upon the pre-Carboniferous border rocks, the frequent parallelism of strikes of the Carboniferous sediments with the trend of the border, and the diversity of overturn and underturn relations at the borders, as exhibited by the axial planes, indicate that the forces which operated through the pre-Carboniferous, whatever their original character, must have been multiple in value and in direction at nearly all places where they encountered the Carboniferous.

(2.) Within the Basin strata these forces acted in all directions, but with much greater intensity along east-west lines than along north-south lines.

(3.) In different parts of the Basin the deformation effected by these forces varies in complexity according (*a*) to variations in the direction and potency of the forces themselves; (*b*) to the texture (and therefore rigidity) of the rock affected; and (*c*) to vertical position in a given fold.

(4.) Variations in the deformation, due to variations in the forces, are so distributed that (*a*) there is a marked increase in the complexity of folding and in the amount of compression from north to south; (*b*) there are approximately north-south alternating belts of more or less intense deformation; and (*c*) within a few miles of the border there is sometimes observable an increase in intensity.

(5.) Variations in the deformation (only minor folding), due to differences of texture, are important, but local. Finer rocks are more highly contorted than coarser ones.

(6.) Variations in the deformation, due to vertical position in the folds, are of little importance and are commonly local. The folding appears to be of the parallel type except in rare instances of very minute crumpling.

(7.) The factors upon which variations in the folding are dependent, mentioned in order of lessening importance, are:

(*a*) relative position of outcrop along north-south lines;
(*b*) rock texture;
(*c*) distance of outcrop from walls of Basin;
(*d*) relative vertical position of outcrop in fold.

Cambridge, Mass., Jan. 6, 1912.

(To be continued.)

ART. XXV.—*The Ilmenite Rocks near St. Urbain, Quebec; A New Occurrence of Rutile and Sapphirine;* by CHARLES H. WARREN.

Introductory.—One of the notable occurrences of ilmenite, mentioned in treatises on mineralogy, is that near Bay St. Paul, a town located on the north shore of the St. Lawrence River, about sixty miles east of Quebec. This occurrence is more accurately located as being just west of the little village of St. Urbain in the parish of that name, which is located about ten miles north of Bay St. Paul on the River Gouffre. In the Geology of Canada, 1863, Dr. T. S. Hunt gives a brief description of this occurrence. He states that the ilmenite bodies are "intercalated in the stratification" of the anorthosite rock in which they occur. One bed, 90 feet thick, was traced for a distance of 300 feet, and was reported continuous for over a mile. Writing further, he states, "it contains in many parts orange-red transparent grains of pure titanic acid." The density is given as from 4·56 to 4·66. A chemical analysis gave: TiO_2 48·60; Fe_2O_3, 10·42; FeO, 37·06; MgO, 3·6. Total, 99·68. Just what type of ore this analysis represents is not stated, but assuming it to be a fairly correct analysis, the molecular ratio derived from it indicates that it was made on rutile-free material. The presence of the rutile appears to have been practically forgotten, at least no other mention of it occurs in the literature so far as the writer is aware. Its presence in the ilmenite was again noted in the summer of 1909 by Dr. W. R. Whitney of Schenectady, N. Y., while on a visit to the locality, and it was through the latter's interest in the deposit that the writer had an opportunity of visiting the locality in the spring of 1910. A representative collection of material was made at that time with the expectation of later using it for a thorough study of this unusual rock. A more careful examination of the material in the laboratory showed it to be more unusual in character than was at first supposed, but, unfortunately, it was also found that the material had suffered so much from alteration that it has been thought best to defer any exhaustive chemical study in the hope that fresher material may eventually be obtained, when it is also hoped that further details regarding the extent of the rutile-bearing portions may be also available.

The Enclosing Anorthosite.—Like so many other occurrences of ilmenite the containing rock of the St. Urbain deposits is an anorthosite. The extent of the anorthosite area in the present instance is not known, but it appears to be a large one, and may be, as was believed by Hunt, continuous with the

anorthosite located near Quebec, just north of the Chateau Richér, and known by that name. It is probably distinct from the great mass of anorthosite lying to the north and northeast about the upper waters of the Saguenay.

The anorthosite calls for no special description. It may be noted, however, that it is rather poor in femic constituents, and that such as occur are largely or wholly altered to chloritic or serpentinous products. The disseminated grains of ilmenite are always highly xenomorphic. Locally the rock shows some crushing, and throughout, the feldspars, which are chiefly andesine, show some evidence of strains.

The Ilmenite Masses in General.—The contacts with the ilmenite bodies are, as a rule, quite sharp, although there is in places some gradation. Along the contacts there is commonly a narrow band of a dark brown mica developed. Small spherical or irregular masses of ilmenite occur at many places in the vicinity of St. Urbain, also narrow dike-like streaks. The larger bodies appear in general to have the form of elongated masses, sometimes dike-like in their general outlines. The elongation follows an indistinct gneissoid structure in the anorthosite, which here has an east-westerly direction. The dip is usually highly inclined, although some of the ore bodies bend over and lie almost horizontally, conforming, doubtless, to local flextures in the enclosing rock.

Large Deposit of Rutile-free Ilmenite.—One of the two most important exposures of the ilmenite rock is found about one-half way up the hillside, which rises rather steeply directly west of the village of St. Urbain and forms the western rim of the broad valley of the River Gouffre. The ilmenite has been partially uncovered, and probably a few thousand tons were mined many years ago for iron. In fact, the ruins of an old smelter may still be seen just below the deposit. The total exposure at the old workings is perhaps 100 feet wide by 200 feet long (east and west.) Good outcrops occur at intervals for some distance to the west along the bed of a small stream which runs down the hillside at this point. On the south side of workings a dike-like body of very massive ilmenite is exposed and may be followed up the hill for some 200 feet. This has an average width of about 10 feet and near its upper end bifurcates, one branch bending off to the northwest. A few feet north of this, another dike, possibly ramifying below with the first, bends off to the north with a flattening dip until it becomes almost horizontal. Just north of this again comes another mass, which has been uncovered over an area measuring some 70 feet on a side, with a depth, as exposed, of some 20 feet. This is cut near its northernmost exposure by a narrow streak of anorthosite rock with a nearly vertical dip and an east-west trend.

Megascopically, the ilmenite rock from this occurrence consists essentially of a dense black, medium to rather coarsely granular ilmenite, through which are scattered small grains of feldspar, or its decomposition products, occasional grains of a dark green spinel, and plates of dark brown mica. Long exposure to surface weathering develops a brown limonite coat, but, as a whole, the ilmenite rock is very resistant to weathering processes. The ore, studied in thin sections and on polished surfaces, shows that the ilmenite, as well as the other constituents, lack altogether any crystallographic outlines. The ilmenite grains range in size from individuals 3–4^{mm} in cross section to ones 10–12^{mm}, the average being perhaps 6–7^{mm}. The feldspar is the same variety as that in the anorthosite and forms rounded grains. It is often largely replaced by secondary products. Lying along the border of many of the feldspar grains, next to the ilmenite, biotite is developed. This may lie parallel to the margin or may project out into the feldspar, sometimes replacing a good portion of it. Its occurrence is such as to suggest that it may be of later origin than the feldspar, developed, perhaps, during the late magmatic period, or during a subsequent period of metamorphism. It possesses a very marked pleochroism and absorption: light brown or almost colorless to deep reddish brown. The axial angle as measured with the microscope was found to be 10 degrees. It resembles closely mica, often observed in a somewhat similar connection elsewhere, and is doubtless an iron rich variety. Alteration changes it to a chlorite. The spinel is of a dull green color, feebly translucent, isotropic, and is to be referred to the variety pleonast. Its grains are entirely without crystalline outlines, and it occurs both with the ilmenite and about the feldspar grains. Quantitative estimates show that considerable portions of the ore will not contain over 2 to 2·5 per cent of accessories, but the general run will carry from 5 to 6 per cent.

Structure and Composition of the Ilmenite Grains.—Examined with a strong direct illumination, polished surfaces of the ilmenite show that individual grains are not of homogeneous composition, although all are identical in character. They are made up of a very fine lamellar intergrowth of two kinds of material. One kind, comprising what is roughly estimated as one-fifth to one-quarter of the whole, is of a bright steel-gray color and follows, as a rule, a nearly straight course across the grains. Many of them pinch out within the grain and in some the strips have the form of very flat, lensiform bodies; again they are slightly curved in outline. In width they vary from 0·003 to 0·02^{mm}. The second series are uniformly broader than the first and run from 0·036^{mm} to 0·09^{mm} in width. These are of a dull black color. The whole intergrowth suggests in

appearance a fine microperthite structure. If a polished surface be immersed in cold dilute hydrochloric acid, the latter very soon shows the characteristic color of ferric chloride, becoming in the course of two or three hours quite strongly colored. The solution gives reactions for ferric iron only. Pure magnetite, similarly treated, dissolves somewhat more readily, but the solution reacts strongly for both ferric and ferrous iron. The steel-gray lamellæ are deepened by the action of the acid forming tiny grooves, indicating that it is this part of the intergrowth that is dissolved. As will be seen from the chemical analysis of the ore given later, the percentage of ferric oxide present is in general agreement with the percentage of the steel-gray lamellæ. These facts point strongly to the conclusion that the latter are *hematite in intimate crystallographic intergrowth with ilmenite.* It may also be noted that the ilmenite grains are not affected by an ordinary magnet, and indeed require a strong field on an electromagnet in order to be attracted to the point of picking up. Their weak magnetic properties indicate quite clearly that there is no magnetite present. The very fine powder rubbed on smooth white paper gives a dull brownish black streak (with perhaps a slight reddish tint) *identical* in appearance with the streak similarly obtained from a mixture of $\frac{3}{4}$ pure magnetite (black streak) and $\frac{1}{4}$ hematite (dark red streak).

To the writer this intergrowth appears to have some interest in connection with the composition of "titanic-irons" generally, and the disputed question of the isomorphism of hematite and ilmenite. While it is impossible to make an exact estimate of the amount of ferric oxide present as such in the intergrowth, the approximate estimate given above agrees approximately with the per cent of ferric oxide found by analysis. From this it appears that the amount of Fe_2O_3 mixed isomorphously with the ilmenite must be small. The excess of Fe_2O_3 so commonly reported in ilmenite analyses has generally been accepted to mean that the ilmenite and hematite molecules are isomorphous. If the ilmenite grains in the present instance possess the structure originally assumed by them on crystallization from the magmatic condition, the idea at once presents itself that the Fe_2O_3 present in ilmenite may be always in large part, at least, present in the form of a fine intergrowth, and the desirability of examining carefully prepared polished and etched specimens of ilmenite whose chemical composition is accurately known is at once apparent. It is of course by no means certain that the intergrowth is an original structure. The two molecules may have crystallized originally as an isomorphous mixture and subsequently, under changed conditions of temperature, etc., being no longer stable in the isomorphous

state, separated, forming the intergrowth described. Such a change may have been considerably facilitated by the metamorphism to which this rock has to some degree been subjected. It is to be noted that, although the two minerals have very nearly the same crystallographic constants, they differ somewhat in symmetry, and the accepted formulæ for the two are not strictly analogous, ilmenite being $RTiO_3$ and hematite Fe_2O_3. It may, therefore, be questioned whether the crystallographic and chemical analogies of the two are sufficiently close to permit of isomorphous mixture to more than a very limited degree, but close enough to condition an intimate and definite crystallographic intergrowth. It is hoped that a further study of the relations existing between ilmenite and hematite and also magnetite when these molecules occur together may soon be carried out.

Deposit with Rutile–Sapphirine–Bearing Ilmenite.—The second, and in the present instance, the most interesting deposit, is located near the top of the same ridge as the previous one, about one-half a mile to the southwest. It has been pretty well exposed for a length of about 300 feet and for 50 feet in width. At one point the ilmenite rock has been opened up to a depth of about 15 feet and to a less depth in several others. Its contacts with the anorthosite, where exposed, have a roughly east and west trend and are nearly vertical. In the ore are several streaks of anorthosite which have also a nearly vertical extension and a more or less marked schistosity following much the same direction. There is also in the ore in places a feebly marked banding with the same trend. Further west and southwest of this deposit several small dike-like masses of ilmenite are exposed with the same orientation, but these carry no rutile, etc.

The mineralogical character of the greater part of the ilmenite rock in this mass is essentially the same as that previously described. The grain, however, appears on the average to be a little finer. A portion of the deposit differs from the rest and from other known bodies of ilmenite associated with anorthosite rocks, in containing a notable percentage of *rutile* and a smaller amount of the rare mineral *sapphirine.*

The rutile-bearing portion was first observed as a streak two feet wide, with a nearly vertical dip and an indistinctly marked banding parallel to the walls which ran east and west. The passage of this streak into the rutile-free ilmenite on both sides was very sudden. Toward the west the rutile-bearing portion widened, and was somewhat less sharply defined, and there is evidence which points to the occurrence of rutile-bearing bands and patches. It appears, however, to always change quite sharply into the rutile-free rock. It was traced for several hundred feet.

Cutting the ore-body in the rutile-bearing portion is a streak of anorthosite rock which itself carries more or less rutile. The rutile makes up from two to three per cent of this rock as nearly as it was possible to estimate it. It is associated with ilmenite and a considerable amount of biotite. These minerals are arranged along distinct lines of schistosity. No sapphirine has been noted in this rock.

The *rutile-bearing rock* is of a brownish black color and consists of a rather finely granular ilmenite thickly sprinkled with grains of an orange-red rutile, a smaller amount of feldspar, biotite, sapphirine, or their decomposition products, and spinel. The sapphirine cannot be distinguished without the aid of a good lens, and then only upon very close inspection, about the feldspar and ilmenite grains in the form of very dark, greenish black grains. The less altered ore is firm, but weathered portions are somewhat friable. All of the material collected shows more or less limonite along cracks and joints. In a limited portion of the rutile-bearing rock fairly numerous plagioclase grains or groups of grains, often larger than the average in size, are present. These feldspars sometimes reach a length of two or three centimeters and one centimeter in width, and are characteristically associated with a strong development of biotite plates.

Microscopic thin-sections of the rutile-bearing rock disclose a highly xenomorphic texture for all of the constituent minerals with the one exception of the spinel inclusions in some of the feldspar grains. The ilmenite forms an almost continuous background in which the other minerals lie. Its grains, although irregular in outline, are roughly equidimensional and are fairly uniform in size, their average cross-section being about 3^{mm}. They consist of the same lamellar intergrowths as previously described, but the two sets of lamellæ are narrower than in the former case, conforming to the smaller average size of the grains. The rutile is in the form of simple crystal grains or clusters of such, and is of a beautiful orange or golden brown color with a barely perceptible pleochroism. The cleavages are prominently developed. Twinning is rare. Individual grains attain a diameter of $3{\cdot}5^{mm}$. From this size they run down to mere specks, the average being in the neighborhood of $0{\cdot}6^{mm}$. It is distributed quite uniformly through the ilmenite and occurs also with the other minerals, being sometimes enclosed in their grains. The spinel is rather sparingly present and forms grains comparable in size to those of the rutile. In the feldspar-rich portions of the rutile-bearing rock, it also occurs included in the feldspars in the form of exceedingly minute crystals. These inclusions deserve a brief description. Many of the feldspars are crowded with them.

They are of a pale, dull green color and as a rule are definitely orientated with reference to the enclosing crystal. Just what the orientation is has not been made out. Many of the spinels have a highly perfect octahedral habit, the whole crystal coming into view with slight changes of focus. Other crystals show the characteristic cross-sections of distorted octahedrons, or form flat, triangular plates. These attain a diameter of $\cdot 015^{mm}$, though usually smaller. Again the spinels have the habit of relatively greatly elongated rods, or somewhat flattened blades arranged in lines across the feldspars. The inclusions are isotropic, although being wholly enclosed in the feldspar, which often exhibits a slight disturbance in its optical properties about the inclusions, they often seem to be slightly doubly-refracting themselves. Minute inclusions of sapphirine have also been noted occasionally associated with the spinels, but these have a different color and are irregular in outline.

The feldspars are an andesine like that of the anorthosite. They are as a rule quite evenly distributed and of fairly uniform size comparable with the ilmenite, but occasionally, as noted, they become more numerous and of larger size, and form groups of grains. Many of them show evidences of strains and slight bending. In even the fresher material collected the feldspar is usually partly replaced by secondary products, particularly where biotite and sapphirine were present with it, and in more highly altered specimens it is entirely gone.

The biotite is sometimes quite abundant and has the same characteristics as previously described. It is most intimately associated with the plagioclase, and where sapphirine is present it appears to have developed later than this mineral. Its position about the margins of the feldspar, or replacing part of it is here, as elsewhere, strongly suggestive of a later secondary origin. Its alteration is to chloritic products.

An occasional grain of apatite has been noted, but it is hardly present as more than a trace.

The *sapphirine*, which is of especial interest here, it being not only a *new occurrence* of this rare mineral, but also in a *new association*, seems to be confined to portions of the ilmenite rock which carry rutile. Even when alteration has destroyed both plagioclase and sapphirine, the characteristic alteration products enable it to be seen that the sapphirine has been a quite constant associate of the feldspar in the rutile-bearing portion. That there is some intimate relation between the feldspar and the sapphirine is shown by the fact that the latter generally lies between the feldspar and the ilmenite. It is often seen as a narrow band extending around the feldspar. (See fig. 1.) The band may widen out into a larger

mass. Again, the feldspar may be surrounded by sapphirine of nearly or quite equal area. About a single feldspar grain the sapphirine usually has, throughout the greater portion of its extent, a uniform orientation. The mineral also includes ilmenite and rutile grains, and in one instance, at least, has been noted in contact with spinel. Where the feldspar is more abundant the sapphirine is also more strongly developed and its grains have in some instances fairly continuous distribution

Fig. 1.

Fig. 1. Microphotograph of thin-section, showing plagioclase (white) almost entirely surrounded by sapphirine (gray) either as a narrow band or as larger grains between it and the ilmenite (black) or rutile (dark, mottled). The plagioclase shows many minute microlites of spinel. Magnif. about 90; ordinary light.

through the section, and often lie, with and without included ilmenite and rutile, between the feldspar crystals, or even included in them. In such sections as much as 20 per cent has been observed with about an equal amount of feldspar and rutile, a little spinel, and the remainder ilmenite. Here, the larger grains frequently attain a diameter of $3{\cdot}0^{mm}$, the aver-

age being somewhat smaller (0·4 or 0·7mm). Quantitative estimates of the amount present indicate something like 3–5 per cent for the general run of the rutile-bearing rock.

No trace of crystallographic outline has been noted on the sapphirine and there is only a faint suggestion of two intersecting cleavages. The fracture is marked, being developed in the form of prominent irregular cracks and is highly conchoidal. The pleochroism is strong, $\mathfrak{a}$, pale, smoky brown to almost colorless, $\mathfrak{b}=\mathfrak{c}$, deep sapphire-blue, sometimes with a shade of green. The single refraction is strong, $\mathfrak{a}$, having been determined by the immersion method as approximately 1·729 for sodium light. The double-refraction is very low, not exceeding 0·005. The interference tints in many sections show deep berlin blues. The optical character is clearly negative, the axial angle rather large, and the dispersion is marked $r < v$. It is to be noted that the index of refraction is higher than that of the sapphirine from the original locality in Greenland in specimens studied by the writer.

The sapphirine from India* corresponds to that of the present locality very closely in color, and the index for $\mathfrak{a}$ has been determined by the writer as about 1·726.

The sapphirine from St. Urbain shows nearly always a more or less extensive alteration not observed in the case of the Indian and Greenland varieties. This begins as a finely fibrous or foliated development along the curved fracture lines and margins. Further alteration develops a fine aggregate of more distinctly foliated material which suggests talc in appearance. These products become mingled with chlorite, biotite and ferruginous material, resulting from the alteration of the associated minerals, which renders it difficult to determine the exact character of the alteration. Nevertheless, the appearance of the alteration is quite characteristic and as noted above, permit it to be easily seen that the sapphirine was originally more abundant than at present.

The alteration of the sapphirine, as well as its intimate association with the other minerals, made it difficult to obtain suitable material for a chemical analysis. By means of an electro-magnet and heavy solutions, some 3 grms. sapphirine contaminated with the other minerals and alteration products were separated from a sample of rutile concentrates, generously placed at the writer's disposal by Mr. E. R. Berry of the General Electric Company of Lynn. In barium-mercuric iodide solution, grains of seemingly pure sapphirine sank just after

* Petrological Study of Some Rocks from the Hill Tracts, Vizagapatam District, Madras Presidency. Walker and Connor, Records Geological Survey of India, vol. xxxvi, Part 1, 1907. The writer is indebted to Professors Walker of Toronto and Palache of Cambridge, Mass., for specimens of the Indian and Greenland minerals which were studied in this connection.

epidote, specific gravity 3·54. Less pure grains continued to sink down to a specific gravity of 3·43. The true specific gravity probably lies somewhat above 3·5.

The material was further purified by fusing its fine powder with sodium carbonate, which has only a slight action on the sapphirine but decomposes the other minerals, including the rutile and the alteration products of the sapphirine. Something over a gram of material was obtained in this manner, which, examined under the microscope, was found to be entirely free from impurities, and upon this a chemical analysis yielded the results given below in column 1. In the other columns are given other analyses of sapphirine.

	I	II	III	IV	V	VI	VII
SiO_2	13·44	14·56	14·51	14·86	14·76	12·95	12·83
Al_2O_3	62·98	60·49	63·11	63·25	63·23	64·44	65·[illegible]9
Fe_2O_3	----	----	Mn_2O_3 ·53	----	---	----	·93
	----	----	CaO ·38	----	----	----	----
FeO	9·08	7·65	3·92	1·99	1·65	1·66	·65
MgO	15·28	17·13	16·85	19·28	19·75	19·83	19·78
Ign	----	·56	·49	----	----	·34	·31
Total.....	100·78	100·39	99·79	99·38	99·39	99·22	99·79
Sp. grs. ...	3·5	3·542	....	3·473	....	3·46	3·486

I—Mineral from St. Urbain, Quebec: Warren.
II— " " India: Walker and Collins, Records, Geol. Surv. of India, vol. xxxvi, Part I, 1907.
III— " " Fiskernäs, Greenland: Stromeyer, Unters., Misch. Mineralk., 1871, 391.
IV— " " Fiskernäs, Greenland: Damour, Bull. Soc. Geol., vi, 315, 1849.
V— " " Fiskernäs, Greenland: Schluttig, Inaug. Diss., Leipzig, xxii, 1884, and Zs. Kr., xiii, 74.
VI— " " Fiskernäs, Greenland: Lorenzen, Medd. Gronl., vii, 184.
VII— " " Fiskernäs, Greenland: Ussing, Zs. Kr., 15, p. 600.

Below are given the molecular ratios derived from the above analyses: FeO has been combined with MgO and listed as RO, Fe_2O_3 and Mn_2O_3 as R_2O_3.

	I	II	III	IV	V	VI	VII
SiO_2	0·224	0·242	0·242	0·247	0·246	0·216	0·214=
R_2O_3	·617	·593	·621	·620	·620	·631	·643=
RO	·508	·534	·475	·508	·516	·517	·502=
SiO_2	2·00	2·00	2·00	2·00	2·00	2.00	2·00
R_2O_3	5·51	4·90	5·13	5·02	5·03	5·84	6·05
RO	4·53	4·41	3·92	4·11	4·19	4·79	4·69

The ratios derived from the analyses of Lorenzen and Ussing (VI and VII) lead to the formula given by them, $Mg_5Al_{12}Si_2O_{27}$, although it is to be noted that there is a considerable deficiency in the RO figure in both cases, and in VI of R_2O_3. The ratios derived from the analyses of Stromeyer (III), Damour (IV), and Schluttig (V) agree rather more closely with the formula $Mg_4Al_{10}Si_2O_{23}$. The ratios of the St. Urbain sapphirine lie about half way between these two formulæ, while those of the Indian mineral depart rather widely from both, although they perhaps favor the second type. Ussing, in discussing the composition of the mineral, attributed the relatively higher silica values of the older analyses of Stromeyer, Damour, and Schluttig to the presence of mica or other impurities. This criticism cannot apply in the case of the St. Urbain mineral, nor apparently in that of the Indian mineral; and as the analysis of the mineral presents no difficulties, it does not seem as if the differences can be attributed to analytical errors. The composition is that of a very basic silicate, and does not appear to conform to any simple formula. It seems probable that there may be some solid solution relation existing between the molecules which make up the mineral; at least this is the only apparent explanation of the variations in composition which it shows.

It may be noted that there are two types of the mineral from Greenland (see Ussing), one of a light blue color, the other having a deeper blue color and occurring in a more ferruginous association. Ussing suggests that the deeper blue color may be due to the presence of more iron in this type, an idea in keeping with the higher iron content of the St. Urbain and Indian minerals.

Origin of the Sapphirine.—In the case of the sapphirine from Fiskernäs in Greenland, the mineral appears to be of metamorphic origin, occurring, according to Steenstrup,* in small ellipsoidal or irregular masses in mica-schist or gneiss, high in MgO and Al_2O_3 but low in silica. Walker, in the paper alluded to, presents strong evidence to the effect that the Indian sapphirine is also of metamorphic (contact) origin, having been formed by the action of ultra-basic, spinel-bearing rocks of the charnockite series, on a sillimanite schist. Its occurrence as a metamorphic mineral in these two instances suggests strongly that it may be also of metamorphic origin at St. Urbain, an hypothesis which is perhaps also supported by the peculiar and intimate association of the mineral with the feldspar. If so, it must represent a reaction product between the feldspar and the spinel, although in the absence of any lime-bearing silicate of a secondary nature, such as epidote or hornblende, it is diffi-

* Medd. om Gronl., Kopenhagen, 1884, vii, 15.

cult to picture the exact character of the reaction which produced it. It is perhaps possible that it was formed by a reaction between the alumina and silica of the plagioclase and the spinel, some sodium and silica being eliminated and the remaining feldspar crystallizing as a somewhat more basic lime-soda feldspar. The optical properties of the feldspar associated with the sapphirine do not indicate, however, that it is more basic than that elsewhere in the ilmenite nor in the enclosing anorthosite. Nor is it at all clear why the sapphirine should not have formed in those portions of the ilmenite rock, also containing the same plagioclase but free from rutile, these having certainly undergone substantially the same metamorphism as the rutile-bearing portions. Taking everything into consideration, the writer believes that the sapphirine in this instance is a magmatic mineral.

Quantitative Study of the Rutile-bearing Rocks.—Two quantitative estimates (Rosival) of the mineral composition of the rutile-bearing rock have been made on large, thin sections, one cut from a sample which appeared richer than the average in rutile, and the other from a rutile-poor sample. The results were as follows:

Rutile	20·4	11·3
Ilmenite-hematite	73·2	84·5
Sapphirine	3·2	0·7
Rest	3·2	3·2
	100·0	100·0

It is certain, as noted, that the sapphirine as judged by its characteristic alteration products was originally more abundant than at present, so that a part of the material listed as "rest" represents sapphirine once present. The average of the percentages for rutile is 15·8 per cent, which is probably not far from the true average rutile content of the rutile-bearing portion.

As stated, it has not been deemed worth while to make at present an exhaustive chemical analysis of the rock on account of its considerable degree of alteration. A fairly complete analysis* has, however, been made on a sample of the rutile-rich type similar to that on which the Rosival estimate, given in column I, above, was made. The results are as follows:

* This analysis was made by Mr. R. S. Anderson in connection with a thesis presented as one of the requirements for graduation in the course in Mining Engineering at the Massachusetts Institute of Technology. The work was done under the supervision of Professor William Hall of the Department of Chemistry, and the writer. Each result is the average of at least two, and in the case of FeO and TiO_2, of three determinations.

	Per cent	Molec. ratio	Ilmenite	Rutile	Hematite	Rest
SiO_2	2·24	0·037	....	....	....	....
TiO_2	53·35	·667	0·382	0·285	....	....
Al_2O_3 ...	1·65	·016	....	....	....	....
Fe_2O_3 ...	13·61	·085	....	....	0·085	....
FeO	24·49	·340 }	·344	....	....	....
MnO	·30	·004 }	....	....	....	....
MgO	4·04	·101	·038	....	....	....
CaO	·30	·007	....	....	....	....
	99·98	....	58%	22·8%	13·6%	5·6%

It is of course impossible, on account of the uncertainty as to the exact amounts of the accessory constituents present and of their composition, also as to the exact composition of the ilmenite molecule, to calculate the true mineral composition of the rock. An approximation may, however, be made by assuming that about one-tenth of the RO in the ilmenite is MgO, calculating the excess of TiO_2 as rutile and of Fe_2O_3 as hematite and neglecting the SiO_2, etc. Such a calculation gives the approximate results shown after the analysis in the table. The percentages summarized are: Ilmenite-hematite, 71·6 per cent; rutile, 22·6 per cent: rest, 5·6 per cent. These results are in fair agreement with the results of the Rosival estimate given in column 1 above. The hematite amounts to about one-fifth of the ilmenite-hematite mixture, which is a figure somewhat lower than that obtained by a very crude estimate made with the microscope on an etched specimen. The results are, as a whole, mutually confirmatory to a quite satisfactory degree.

While no attempt will be made at this time to classify the rock in the "Quantitative System," it is easily seen that it falls in a new position in the perfemane class, perhaps in close company with the interesting ilmenite-rutile-apatite rocks recently described* from Virginia by Dr. Watson. In view of the occurrence of so much free titanic oxide as primary rutile, it appears to the writer that it will be necessary to give TiO_2 a special significance in classifying this and analogous rocks in the "Quantitative System."

Origin, Crystallization, Name.—That the ilmenite masses in general so commonly associated with anorthosite or gabbroid rocks are the result of magmatic differentiation seems to be generally accepted. In the case of the rutile-sapphirine-bearing portion there appears to be no good reason to doubt that it represents a portion of one of these differentiated masses in which there was a notable excess of titanic oxide and a somewhat smaller excess of magnesia and alumina.

* U. S. G. S., Bull. 430, p. 206, et seq.

The texture of the rocks are thought to represent substantially that which developed upon crystallization from a magmatic condition. Like so many anorthosites the present one has undoubtedly been subjected to more or less dynamic action, but it does not seem to have been particularly severe about and in the ilmenite rocks. The rutile grains show no sign of strains nor crushing. Granting for the ilmenite-hematite intergrowth a secondary origin, which is open to question, its development could not have much, if at all, modified the original texture of the rock. The feldspar also shows but little evidence of severe strains or crushing. Furthermore, if we assume that both the sapphirine and the biotite are due to secondary reactions, during or subsequent to the actual crystallization of the magma, the changes involved are clearly incompetent to account for the formation of the rutile as a secondary mineral; nor is there any other evidence of mineralization or chemical changes adequate to produce it. It is, furthermore, most unlikely that if the rutile is of secondary origin its occurrence would be confined to portions of the mass, the remainder of which has been most surely subjected to the same dynamic and metamorphic action.

It is believed that the rutile-sapphirine-bearing rock represents a magmatic crystallization, and as such it is a new and extreme ultra-basic type, which is deserving of a distinct name. Accordingly the name *Urbainite* is proposed for it, with the expectation that the same stem will be used with an appropriate termination for its designation in the "Quantitative System" so soon as fresh material can be secured for a satisfactory chemical analysis.

Without going into a discussion of the question here, the writer ventures to express the opinion, founded in part on the textural and mineralogical evidence above presented, that these masses of ilmenite rock, if they are, as now believed, products of magmatic differentiation, have crystallized as units from partial magmas of like composition to the resulting rocks subsequent to their differentiation from the parent anorthosite magma, and that they have not been formed by the gradual accumulation of separate grains through a process of fractional crystallization.

Summary.

I.—Large masses of rock consisting largely of titanic-iron ore occur in anorthosite in the Parish of St. Urbain, Province of Quebec, Canada. These masses have in general an elongate form, sometimes dike-like, conforming to the structure of the enclosing rock.

II.—In the main they consist of ilmenite, hematite, with accessory andesine, green spinel and biotite. Throughout a con-

siderable portion of one of these masses, rutile is an essential and abundant constituent (ca. 15 per cent). In such there is also present a smaller (3–5 per cent) amount of the rare mineral sapphirine. The latter may be very abundant in certain limited portions of the rutile-bearing rock where plagioclase is also more abundant. It is intimately associated with the feldspar, commonly lying about its grains, often as a narrow band, and separating it from the ilmenite. Rutile is also present with ilmenite and biotite in a stringer of anorthosite closely associated with the rutile-bearing ilmenite rock.

III.—The rutile-sapphirine-bearing rock forms quite sharply defined portions of the ilmenite rock and appears to be of magmatic origin, representing a part of the segregation exceptionally rich in titanic oxide, to a less extent in magnesia and alumina, and deficient in silica.

IV.—A new occurrence of sapphirine is recorded and in a new association. Although possibly of metamorphic origin, like the sapphirine in the two occurrences previously known, it is thought in the present instance to be of magmatic origin. A chemical analysis made on material of exceptional purity shows that it resembles closely the sapphirine from the Hill Tracts, Vizagapatam District, India. It is pointed out that the molecular ratios derived from the analysis and from that of the Indian mineral show a considerable departure from the one usually accepted for the mineral, and do not correspond to any simple formula, and the existence of solid solution relations between the molecules making up the mineral are suggested.

V.—Microscopic and chemical evidence is presented to show that the titanic-iron of these rocks consists of an intimate, very fine, lamellar crystallographic intergrowth of ilmenite and hematite, in which the hematite makes up something like one-fifth of the mixture. It is pointed out that this relationship suggests that the Fe_2O_3 in so many ilmenites may be in large part, at least, present as hematite crystallographically intergrown and not as an isomorphous mixture.

VI.—A chemical analysis of the rutile-bearing rock, also quantitative estimates of the mineral composition as determined with the microscope, are given. These are in fair agreement, and show that the rock is unique in composition, and represents an extreme and new ultra-basic type of igneous rock. The name *Urbainite* is proposed to designate rocks of this type.

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SCIENTIFIC INTELLIGENCE.

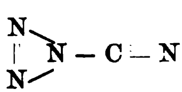
I. Chemistry and Physics.

1. *The Quantitative Determination of Manganese in the Form of Various Oxides.*—Raikow and Tischkow have found that the higher oxides of manganese are reduced to MnO by ignition in a stream of hydrogen in a Rose crucible. The reduction is hastened to a certain extent by increase in temperature, but it depends chiefly upon the speed of the stream of hydrogen, so that with a rapid stream of hydrogen the reduction is complete in a few minutes, even with the moderate heat of a Teclu burner, and the MnO is entirely homogeneous and of a pale green color. This novel form for weighing manganese is recommended by the authors as one of the most accurate.

The conversion of manganese oxides into Mn_3O_4 has also been studied. It was found that MnO is converted quantitatively into the protosesquioxide by ignition in the air over the blast-lamp, but that, if the temperature is not high enough, oxidation to Mn_2O_3 gradually takes place. However, by igniting a higher oxide in a stream of dry carbon dioxide in a Rose crucible with a Teclu burner, pure Mn_3O_4 is obtained, and this method of weighing manganese is also recommended as accurate.

The authors have found that the oxides of manganese, when heated in the air for a long time by means of a Bunsen burner, are quantitatively converted into Mn_2O_3, and that this conversion takes place more rapidly in a stream of oxygen. The conversion of manganese carbonate into Mn_2O_3 can be accomplished by heating in an oxygen atmosphere, at first strongly with a Bunsen burner, and then at a red heat. The Mn_2O_3 is deep black and entirely homogeneous. The conversion of manganese sulphate into Mn_2O_3 is not so simple. It must be ignited alternately for about 5 to 10 minutes in hydrogen and then in the air, and when no more SO_2 is given off by ignition in the air it can be brought into the form of Mn_2O_3 by ignition at a red heat in oxygen.—*Zeitschr. analyt. Chem.*, li, 135. H. L. W.

2. *A Pernitride of Carbon.*—G. Darzens has announced the preparation of cyanogen trinitride, CN_4, which according to the present views has the structural formula



The compound was easily prepared by the reaction of sodium trinitride with cyanogen bromide in aqueous solution.

$$NaN_3 + BrCN = N_3CN + NaBr.$$

The reaction is accompanied with the disengagement of considerable heat, and when it is complete the solution is extracted with ether, and after the ether has been dried with anhydrous sodium sulphate, it is distilled off under diminished pressure, leaving the carbon tetranitride in the form of a white crystalline body. It melts at 35·50° C., commences to decompose at 90° C., and detonates violently at 150° C. The danger of explosion is such that only small quantities, two or three tenths of a gram, should be prepared in a single operation.—*Bulletin*, xi, 4. H. L. W.

3. *Portland Cement.*—E. Jänecke has made an extensive study of cement clinker and has reached the conclusion that a compound $8CaO.2SiO_2.Al_2O_3$, melting at 1382° C., is the important constituent of this material. This is believed to be an actual compound rather than an eutectic mixture, because it melts at a higher temperature than the mixtures that approach it in composition. The compound has been previously noticed by Törnebőhm as a constituent of cement and called by him "alite." The author says there is no great difficulty in making a constitutional formula for the compound, and advances a provisional one containing four rings, two of which are like the following one :

$$\mathrm{Ca}<\begin{matrix}\mathrm{O-Ca-O}\\ \mathrm{O-Ca-O}\end{matrix}>\mathrm{Si}<$$

In the opinion of the reviewer it would be preferable, since the structure is entirely unknown, to give the simplest formula consistent with valency, for exàmple the following :

$$\begin{array}{lll}
 & \diagup\mathrm{O-Ca-O-Al=O} & \\
\mathrm{Si} & <\begin{matrix}\mathrm{O-Ca}\\ \mathrm{O-Ca}\end{matrix} & >\mathrm{O} \\
 & \diagdown\begin{matrix}\mathrm{O-Ca}\\ \mathrm{O-Ca}\end{matrix} & >\mathrm{O} \\
 & \diagup & \\
\mathrm{Si} & <\begin{matrix}\mathrm{O-Ca}\\ \mathrm{O-Ca}\end{matrix} & >\mathrm{O} \\
 & \diagdown\mathrm{O-Ca-O-Al=O} &
\end{array}$$

Furthermore, the formula just given has a theoretical advantage in allowing for a simple combination with water in the setting of the cement, while in the complicated ring formula such a combination with water would appear to be much less simple.—*Zeitschr. anorgan. Chem.*, lxxiii, 200. H. L. W.

4. *Annual Report of the International Committee on Atomic Weights for 1912.*—The committee, Clarke, Ostwald, Thorpe, and Urbain, give a summary of the work on atomic weights that has been published during the past year. It deals with 18 elements, and is of considerable importance. It is interesting to notice that their International Table for 1912 contains 82 elements. The single one added to last year's table is Niton, the radium emanation, to which the weight 222·4 is given. The changes made since last year are : calcium 40·07, erbium 167·7, iron 55·84, mercury 200·6, tantalum 181·5, and vanadium 51·0. H. L. W.

5. *The Hydrates of Sodium Carbonate.*—WEGSCHEIDER has recently discussed the compounds of sodium carbonate with water of crystallization, and has reached the conclusion that besides the stable salts $Na_2CO_3.H_2O$ (thermonatrite) and $Na_2CO_3.10H_2O$, only one unstable hydrate, $Na_2CO_3.7H_2O$ has been certainly established. A considerable number of other hydrates have been described, all of which appear to have been mixtures of two hydrates or of a hydrate with mother-liquor.—*Zeitschr. anorgan. Chem.*, lxxiii, 256. H. L. W.

6. *Canadium.*—In connection with the announcement mentioned in this department last month, of the discovery of "canadium," a supposed new element of the platinum group, attention has been called to "amarillium," an alleged new element discovered by Courtis in a copper carbonate ore from the Frazer Claims, Similakameen, British Columbia, in 1903.* This was described as having properties somewhat similar to those of "canadium," and it was believed to form a link between the platinum-palladium and the iron-nickel groups of metals. Nothing further has been heard of "amarillium," so that it may be presumed that it did not prove to be a new element.—*Chem. News*, cv, 36. H L. W.

7. *The Intrinsic Brightness of the Starlit Sky.*—Important researches have been made in recent years on the number and distribution in the sky of stars of different magnitudes. The statistical data which serve as a basis for the calculations are so difficult to obtain that it is a matter of importance to find a direct verification of them. Such a verification may be sought by measurement of the mean intrinsic brightness of the sky in different regions of the celestial sphere. In 1903 Townley applied photographic processes to the solution of this problem, but, since his exposures required one hour, the method recently devised and tested by C. FABRY seems preferable and very promising.

The apparatus used is extremely simple, and it may be briefly described as follows: A lens or telescope objective of focal length 48^{cm}, and aperture 5^{cm}, is mounted at one end of a tube which projects at its other end into a suitable box. This box is closed on the inside by a transverse diaphragm, which is pierced by a circular aperture whose diameter can be varied at will and whose center coincides with the principal focus of the telescope objective. On the side of the diaphragm more remote from this lens an optical system of short focus and large aperture is affixed. Because of the rôle which this system plays, Fabry calls it the "microscope objective" and says: "It is not necessary that this objective should have good optical qualities; it consists, in my apparatus, of two simple lenses, each of 20 dioptrics, forming a system of focal distance $f=3{\cdot}15^{cm}$, and of $3{\cdot}5^{cm}$ usable diameter." This lens system projects on a photographic plate an image of the telescope objective. The image is uniformly illuminated and of 3^{mm} diameter, irrespective of the diameter of the

* Trans. Amer. Inst. Min. Engrs., xxxiii, 347.

aperture in the diaphragm and of the distribution of stars in the region observed. The whole apparatus forms a sort of photographic telescope, mounted on a simple, jointed support which is furnished with levelling screws. A coudé finder, attached to the apparatus, makes it possible to point towards any desired region of the sky and, in particular, to center the image of a selected star exactly on the opening of the diaphragm.

Two successive exposures are required to determine the intrinsic brightness of the sky. One exposure is taken when the image, formed by the telescope objective, of a comparison star is focused exactly on the center of the aperture in the diaphragm, the latter being cut down to the same diameter as the image. The image on the photographic plate is then produced solely by the light of the star. The other exposure is made with a large aperture when the telescope is pointed towards the region of the sky to be investigated. In this case, the image on the plate is due to the light of all that portion of the celestial sphere which is projected through the aperture. By varying the radius of the aperture it is possible, after a few trials, to obtain the same density of negative for a certain projected area of the sky as for the comparison star, the time of exposure being exactly the same in both cases. It is then a very simple matter to calculate the luminous intensity of one square degree relative to the standard star. Fabry used *Polaris* for reference and found that, for the non-galactic sky, an aperture of diameter 3^{cm} gave satisfactory results with 10 minute exposures on "Sigma" Lumière plates. There are other ways of experimenting with this apparatus which depend upon the photographic law of reciprocity; but it seems superfluous to describe them in detail because of their obvious nature.

Fabry has tested his apparatus on two regions of the sky, one near the star ϵ *Ursae Minoris* in galactic latitude 30°, and the other between β and λ *Cygni* in the Milky Way. After comparing his results with those obtained visually by Newcomb and by Burns, he concludes that the agreement is as good as could be expected under the circumstances. It may be remarked, however, that there is an unexplained lack of accord between the results of statistical investigations and of direct determinations of the intrinsic brightness of the sky.—*Astrophys. Jour.*, vol. xxxi, p. 394.

H. S. U.

8. *Magnetische Spektren der β-Strahlen des Radiums.*—It has been shown by von Baeyer, Meitner, and Hahn that the "magnetic spectra" of the β-rays emitted by the members of the thorium series are, in almost all cases, discontinuous. For β-rays having speeds equal to, or less than, about 70 per cent of the velocity of light the spectral bands are very well defined, but for the very rapidly moving β-rays the images are comparatively indefinite and "washed out." The above named investigators have since turned their attention to the β-rays projected on the occasion of the disintegration of certain members of the radium series and have obtained the interesting results summarized below.

As a consequence of previous work, by various experimenters, on the absorption of β-rays coming from the radium family, it was expected that three groups of bands, pertaining respectively to Ra, RaB, and RaC, would be found in the magnetic spectrum. A photographic negative obtained with the active deposit of radium, when a field of about 107·5 gauss was used, showed 9 bands for the β-rays in addition to the single stripe which was produced by the practically undeviated α-rays. On another negative, corresponding to a field of 215 gauss, it was possible to measure the magnetic linear dispersion of 7 β-ray stripes or bands. The greatest deviation was, in this case, about 5^{mm}. The negative is reproduced in the paper and most of the bands show quite distinctly. By appropriate, and rather obvious methods, the authors identified the rays which pertain to radium B and C respectively (both of these "elements" being present in the active deposit). For radium C there were four discrete pencils of β-rays having speeds of 98, 94, 86, and 80 per cent of the velocity of light. Radium B was associated with the following speeds: 74, 69, 63, 41, and 36 per cent of 3×10^{10} cm/sec. Lastly, the magnetic spectrum of radium itself was investigated. The reproduction of the negative shows two well-separated stripes corresponding approximately to speeds of 65 and 52 per cent of the velocity of light. In conclusion it may be remarked that additional interest attaches to this series of experiments because in the earlier investigations of Kaufmann, Bucherer, and others the discontinuity of the magnetic spectrum had not been detected.—*Physikal. Ztschr.*, Dec. 1, 1911. H. S. U.

9. *The Production of Characteristic Röntgen Radiations.*—In an earlier paper R. WHIDDINGTON gave a detailed account of his investigation of the production and properties of soft Röntgen radiation (Proc. Roy. Soc., vol. lxxxv, pp. 99–118). He has since extended his research on X-rays to the chief properties of characteristic radiations. These properties may be stated as follows: (a) It is only when the primary rays contain a constituent more penetrating than the characteristic to be excited that the stimulation can be effected. (b) The penetrating power of a characteristic radiation increases with the atomic weight of the emitting element. (The adjectives "homogeneous" and "fluorescent" are often used, in this connection, in place of "characteristic.") The experiments described define the quality of the softest primary radiation which can stimulate a characteristic, in terms of the speed of the cathode rays within the exciting X-ray tube.

Certain parts of the apparatus used merit a brief description. The cathode rays were produced in a discharge tube which was fitted with a special hardening device (loc. cit.). By this means the speed of the cathode rays could be instantly changed to almost any desired value *without altering the gas pressure.* The cathode rays were admitted through a horizontal, radial tube into a brass cylinder whose axis of revolution was horizontal. The outside of this cylinder was wound with a solenoid so that a uniform mag-

netic field would be established at right angles to the incoming cathode rays when a steady current flowed through the solenoid. These rays were spread out into a "magnetic spectrum" since they possessed different speeds; each speed corresponding to a circular trajectory lying in a vertical plane and having its center in a vertical line tangent to the cylinder near the mouth of the inlet tube. The cylinder was provided with a vertical, radial outlet tube which opened into the cylinder at its lowest element of surface and in the plane of the magnetic fan or spectrum. Consequently only such rays as were deviated through about one right angle could escape from the cylinder. By varying the current in the solenoid and by altering the hardness of the discharge tube it was possible to send through the outlet tube a pencil of cathode rays containing approximately one speed, this speed being of practically any desired value. The emergent pencil entered a Faraday cylinder, impinged upon an inclined, silver anticathode and excited the primary X-rays. A beam of these Röntgen rays was allowed to pass through a thin aluminium window and to fall upon a plate of the secondary radiator under investigation. The actual measurements were not novel and therefore further experimental details would be superfluous.

The elements employed as secondary radiators were aluminium, chromium, iron, nickel, copper, zinc, and selenium. For each secondary radiator a curve was plotted with abscissæ proportional to the fourth power of the speed of the cathode rays which gave rise to the primary X-rays. The ordinates were proportional to the energy of the secondary Röntgen rays. In general, the portions of the graphs nearest to the axis of abscissas are decidedly curved, being concave towards the axis of energy. As soon as the energy attains a certain value, depending upon the material of the secondary radiator, the graphs change into straight lines and continue to be straight for all higher values of the speeds of the cathode rays. The curved portions of the graphs are ascribed to scattered Röntgen radiation whose absorption coefficient diminishes as the speed of the cathode rays increases. Special care was taken to determine from the graphs the critical values of the speeds, that is, to determine the points at which the graphs change from curves into straight lines.

The results of this series of experiments may be summarized as follows: (a) "The energy emitted in the form of Röntgen radiation by a cathode particle when suddenly stopped is proportional to the fourth power of its velocity." (b) "The primary rays from a Röntgen ray tube can only excite the radiation characteristic of a radiator of atomic weight w when the velocity of the parent cathode rays exceeds $w \times 10^8$ cm/sec." "This law holds fairly closely for the radiators Al, Cr, Fe, Ni, Cu, Zn, and Se."

Result (a) was deduced theoretically by Sir J. J. Thomson and published in the Philosophical Magazine for August, 1907.—*Proc. Roy. Soc.*, vol. lxxxv, p. 323, 1911. H. S. U.

10. *Weitere Messungen über Wellenlängennormale im Eisenspektrum.*—It was resolved in 1907, at the Meudon meeting of the

International Union for Solar Research, to take as secondary standards of wave-length the means of the data obtained by interferometer methods at three independent laboratories. The radiations were to be obtained from the iron arc under specified conditions, and the primary standards were to be the three cadmium lines which had been measured with an extremely high degree of accuracy, first by Michelson and later by Benoît, Fabry, and Perot. Fabry and Buisson, at Meudon, determined the wave-lengths of 115 lines (chiefly due to iron), from λ 2373·737 to λ 6494·994. Eversheim at Bonn and Pfund at Johns Hopkins took up independently the same problem. The final means of the three sets of determinations were tabulated in the Astrophysical Journal for October, 1910. These means comprised 49 lines from λ 4282·408 to λ 6494·993 inclusive. At this time the wave-lengths of the ultra-violet lines as determined by Fabry and Buisson had not been verified by Eversheim and Pfund.

Very recently Eversheim has published the wave-lengths of 26 iron lines from λ 3370·787 to λ 4282·408. In order to work in the ultra-violet the glass portions of the apparatus were replaced by quartz. The interferometer plates were obtained by subjecting the quartz to a special process of fusion and pressing. A noteworthy improvement in the interferometer proper consisted in making the emergence "plate" in the form of a plano-convex lens, which was half-silvered on the plane surface, of course. This device did away with one lens and minimized several possible sources of error. Another improvement was made in the silvering process. Eversheim says that the receipt was sent to him in a private communication from Pfund. The details are given in the paper under consideration. The cadmium and iron radiations were photographed simultaneously. Finally, the corrections for the variations with wave-length of the change of phase on reflection were very carefully determined by studying the interference curves of equal thickness, so-called.

The extremes of the probable errors of the newly measured lines are given as 0·0002Å and 0·0010Å. The greatest arithmetical difference between the wave-lengths of the same lines as determined by Fabry and Buisson and by Eversheim amounts to 0·003Å, while the simple average of the numerical differences only equals 0·0014Å. Five wave-lengths have identically the same values. The interferometer method seems, therefore, to be about as reliable in the ultra-violet as in the visible spectrum. Eversheim expresses the hope of extending his table up to λ 2300 as soon as possible.—*Ann. d. Phys.*, No. 15, 1911. H. S. U.

11. *The Sun's Energy-Spectrum and Temperature.*—The distribution of energy in the solar spectrum outside of the earth's atmosphere has been deduced by C. G. Abbot from the spectrobolometric observations made at Washington, Mount Wilson, and Mount Whitney during the interval 1903 to 1910. The corresponding means obtained at each of these three stations agree with one another as well as do the constituent data used to calcu-

late the means for any one observatory. The mean intensities of radiation have been investigated for 18 wave-lengths comprised between, and inclusive of, the limits 0·30 μ and 2·50 μ. The solar energy-spectrum is plotted together with the theoretical curves for a black body at temperatures of 6200° and 7000° absolute Centigrade. For the adopted mean spectrum-energy-curve the maximum of energy falls at 0·470 μ.

Using the Wien displacement formula, $\lambda_m T = 2930$ ($\lambda_m = 0{\cdot}470\mu$), the effective solar temperature is found to be 6230° absolute Centigrade. If, on the other hand, the Stefan formula for total radiation, $E = 76{\cdot}8 \times 10^{-13} T^4$, be employed, the aforesaid temperature comes out 5830° absolute. (In making this calculation Abbot uses the following numbers: solar radius $= 696 \times 10^3$ km, mean radius of earth's orbit $= 14{,}956 \times 10^4$ km, and the solar constant $=$ 1·922 calories per cm^2 per min.) In his summary Abbot says: "The conclusion is drawn from the observations cited that the sun's emission approximates roughly to that of a "black-body" at 6000° absolute Centigrade, but that on account of influences probably active, we ought to assign a solar radiating temperature of the order of 7000° absolute Centigrade." The discussion by Abbot of these probable sources of error is too long to be reproduced here; suffice it to say that, in general, these influences would lead us to too low a value for the mean solar temperature. —*Astrophys. Jour.*, vol. xxxiv, Oct. 1911, p. 197. H. S. U.

12. *College Physics;* by JOHN OREN REED and KARL EUGEN GUTHE. Pp. xxviii, 622. New York, 1911 (The Macmillan Co.). —Since the authors have deemed it wise to present the chief divisions of the subject in a rather unusual sequence, it seems fair and pertinent to make the following quotation from their preface. "Owing to the more obvious relations existing between them, the subject of heat is made to follow immediately after the distinctly material phenomena of mechanics and sound; electricity precedes light, and the subject of radiation, usually found under the different chapters of heat, electricity and light, is treated separately after these subjects have been presented." "It has also been thought best, even at the sacrifice of historical consistency, to begin the subject of electricity with current electricity, in order to secure the advantage of the greater familiarity of the student with the phenomena of applied electricity."

Certain other salient features of the book merit enumeration. References are frequently made, by means of unobtrusive footnotes, to the laboratory experiments described in Reed and Guthe's "Manual of Physical Measurements," (3d edition, George Wahr, Ann Arbor.) Numerous references to original papers are also made in the foot-notes, to the end that the student may acquire interest both in the historical and critical aspects of scientific investigation. Several of these references presuppose a reading knowledge of scientific German. The text assumes an acquaintance, on the part of the student, with a few formulæ of plane trigonometry and with the calculus notation of deriva-

tives. The table of contents is followed by a convenient list of the 20 tables of physical constants which are distributed throughout the volume. 294 problems, with the numerical answers given, are placed immediately after the explanations of the principles which they involve.

Attention should be called to the fact that in certain minor details the authors diverge from custom, just as the above quotation shows that they have done in the arrangement of the general subject-matter. For example, speed and velocity are differentiated respectively by the symbols v and $\mathbf{v}$. Formulæ for uniformly accelerated motion are written with double signs, as "$s = v_0 t \pm at^2/2$", thus giving to "a" an arithmetical rather than an algebraic significance. The same preference for arithmetic over algebra is emphasized by the authors' italics in the following sentence of page 417: "The potential, due to all the charges, is simply the *arithmetical sum* of the potentials due to the individual charges." H. S. U.

II. Geology and Mineralogy.

1. *The Geology of the Lake Superior Region;* by Charles Richard Van Hise and Charles Kenneth Leith. Monograph LII, United States Geological Survey. Pp. 641, pls. xlix, figs. 76. Washington, 1911.—This work brings into one volume the results of the studies which have been carried forward since the organization of the national survey. The great economic value of the region, its structural complexity, and the absence of fossils have resulted in concentrating upon it probably a greater amount of study than upon any other area of similar size in the world. There is displayed, furthermore, an unusually complete succession of pre-Cambrian rock systems reaching back to the Archean, making the region one of high general and theoretic as well as economic interest. The authors, who more than any other men have advanced the knowledge of Lake Superior geology, have completed an admirable piece of work in this volume. In it is not only collected a résumé of the descriptive geology of the various districts, but there is given also a discussion of the genesis of the iron, copper, and silver ores and the conditions of sedimentation which prevailed through the successive periods.

The region which is discussed embraces about 181,000 square miles and is accompanied by a general geological map on a scale of 1 to 1,000,000. In an enumeration of certain features of the volume, attention should be called to Chapter IV, Physical Geography of the Lake Superior Region, by Lawrence Martin, which deals with the several baselevels of erosion, the resulting relief, and the origin of the present Lake Superior Basin. Chapters V to XIV inclusive give the geology of the several iron districts. Chapter XV contains sixty-one pages on the Keweenawan series.

Chapters XVII, XVIII, XIX discuss the iron, copper, and silver ores, W. J. Mead coöperating in the chapter on iron ores; and chapter XX gives a résumé of the general geology.

From the mass of valuable material contained within this monograph may be singled out for special mention a few points of novel interest. As a result of studies of a theoretic nature and laboratory experiments in addition to field observations, it is believed that the iron ores were mostly deposited as marine formations and the iron salts rapidly extracted from lavas while they were still hot, partly from juvenile emanations. Ordinary surface weathering seems to have played but a small part in the initial concentration. In regard to the formation of greenalite the chemical studies are especially instructive, as it was found possible to produce artificial greenalite. The reaction of salt water upon hot basalts or porphyries results in sodium silicate. This reacts directly with soluble ferrous salts, for instance $FeSO_4$, and produces a mixture of ferrous silicate aud free silica. If a soluble magnesium salt is also present it is added to the precipitate, explaining the presence of magnesia in greenalite. This was the dominant original mineral and is still abundant, but secondary concentrations have resulted from oxidizing and hydrating of the iron minerals in place, leaching the silica, and convergence of iron carried temporarily in solution. The hematite and magnetite ores are the end results.

Under the chapter on general geology may be noted the discussion as to the dominantly igneous character of the Archean. It was followed by a period of uplift and profound erosion which planed across the older structure. Upon this was laid down the Lower Huronian, regarded by the authors as a terrestrial deposit north of Lake Superior, as a series of marine formations on the south. Following this period and separated from it and from each other by great unconformities came the Middle and Upper Huronian considered as dominantly marine, and the Keweenawan, looked upon as dominantly terrestrial. The characters of many formations change in passing from south to north, and the authors regard this as of probable significance in the great development of the iron ores in this region rather than over the great Canadian shield. "The Lake Superior region, then, may be regarded broadly as a part of a great metallographic province containing a variety of ores associated with volcanism, which may be associated with folding along an old shore zone." J. B.

2. *The Elastic-Rebound Theory of Earthquakes;* by Harry Fielding Reid. University of California Publications, Bulletin of the Department of Geology, vol. vi, No. 19, pp. 413–444, 1911. —In this text, elaborated from a lecture given at the University of California, Professor Reid presents in briefer form that theory of the movement causing the California earthquake which he has published in the report by the Carnegie Institution. He here gives it a greater degree of generality and shows how certain other earthquakes conform to the theory of a slow progressive

movement between crust blocks with accumulating strain, the earthquake being the result of a breaking accompanying relief of strain and involving in the sudden movement only a limited zone of strain between two crust blocks. J. B.

3. *La Sismologie moderne* (*Les tremblements de Terre*); par le *Comte de Montessus de Ballore*, Director of the seismologic Bureau of the Republic of Chili. Pp. 284, pls. and figs. 64. Paris, 1911 (Librairie Armand Colin).—The author of this work is well known as a student of earthquakes, and the purpose which he has had in writing this very readable book is indicated in the preface. Such great catastrophes as that of Messina have awakened a wide interest in earthquakes, but in France no popular work of an authoritative nature has previously met this demand. J. B.

4. *Periodic Variations of Glaciers.*—The condition of glaciers with reference to stages of advance and retreat has been recorded by the International Commission on Glaciers for the year 1910 (Zeitschrift für Gletscherkunde, vi, pp. 81–103, Dec. 1911. In the Swiss Alps, of 54 glaciers observed, 16 show actual or probable increase as compared with an average of 10·3 per cent for the years between 1897 and 1909, while only 36 show actual or doubtful decrease, as compared with 55, the average for the 13 years previous. In the eastern Alps a single glacier on the Wildspitze, reported as advancing in 1909, has been joined by two others; 9 are stationary as compared with two in 1909, while 22 out of 34 under observation are known to be retreating. The glaciers about Mt. Blanc considered as a whole show a decrease. The five glaciers observed in Sweden have advanced and the measurement of the Norwegian glaciers gives the following results: Jotunheim, 4 advancing, 23 retreating; Folgefond, 2 advancing; Jostedalbrae, 8 advancing, 6 decreasing; Okstind Mountains, 4 increasing, 2 decreasing.

In North America the few glaciers reported from the Rockies and the Cascades, also a number north of Juneau and near the headwaters of Copper River, are retreating, while in the Fairweather range in the Yakutat Bay region and on Copper River the glaciers exhibit an advance. The advance of 9 glaciers in the Yakutat Bay region is believed to be due to accessions from avalanches resulting from the earthquakes of September 1899. The glaciers about Prince William Sound give some indication of a general but not very large advance.

This record of glaciers for 1910 needs to be supplemented by reports from other parts of the world, but the data at hand indicates that while there is no general advance yet the decrease in length and mass of existing glaciers which has been continuous for the past two or three decades is not being maintained.

H. E. G.

5. *Interpretation of Peneplains.*—The studies of Mr. E. C. Andrews in the analysis of corrasion and the interpretation of topographic forms carved by water and by ice are important con-

tributions to the science of physiography. In a recently published paper, Erosion and its Significance (Jour. and Proc. Royal Soc. N. S. Wales, xlv, pp. 116–136, 1911) the factors involved in the interpretation and correlation of peneplains are discussed. The conclusion reached is expressed as follows: "Whenever two peneplain or [old age] surfaces are found associated in resistant rock structures, such as granites, crystalline schists, and dense quartzites or sandstones, and the two such surfaces are situated one above the other and the two are separated by a youthful or mature topography, it may be considered that they were formerly continuous, but are now discontinuous, owing to earth processes other than those due to erosive activities. Such earth processes may be either warping or faulting. This is absolutely irrespective of any irregularity of plan possessed by the youthful topography separating the two peneplains." (p. 131).

Mr. Andrews announces that a paper on the physiographic criteria of faulting is in preparation. H. E. G.

6. *Australia in its Physiographic and Economic Aspects;* by GRIFFITH TAYLOR. Pp. 256; 60 figures. Oxford, 1911 (Clarendon Press).—The continent of Australia receives scant treatment in standard atlases and reference books. Much of the published geology and geography consists of detailed studies of disconnected areas and the economic studies are in large part statistical. The book by Mr. Taylor will therefore find a place among geographers and other students interested in the relation of man and his activities to the topography, climate and products of the region in which he dwells.

Chapters I–XI treat of Physiographic Aspects, including climate, vegetation, and regional treatment of physiographic provinces. Economic Aspects are discussed in Chapters XIII–XXIV, under the headings: stock raising, agriculture, mining, transport, and minor industries.

As regards possibilities for settlement, the combined Australian provinces are divided as follows: Arid, 44 per cent—24½ per cent useless, 19½ per cent useless in bad seasons; 17 per cent suited for tropical agriculture; 39 per cent suited for profitable white settlements, i. e. 28 per cent good pastoral land, 11 per cent good farming land. When the geographic conditions are viewed as a whole, it is considered possible that the present population of 5,000,000 may reach 19,000,000 before the close of the century. H. E. G.

7. *Canada, Department of Mines;* WILLIAM TEMPLEMAN, Minister of Mines.—The list given below includes the publications of the Canadian Department of Mines received since the last enumeration (vol. xxxi, p. 574). (1) In the GEOLOGICAL SURVEY BRANCH, R. W. BROCK, Director:

Summary Report of the Geological Survey Branch of the Department of Mines for the calendar year 1910. Pp. 314; 8 figures and 1 map.

Report on a part of the North West Territories drained by the Winisk and Attawapiskat Rivers; by WILLIAM MCINNES. Pp. 58; 5 plates, 1 map.

Report on a Traverse through the southern part of the North West Territories from Lac Seul to Cat Lake in 1902; by ALFRED W. G. WILSON. Pp. 25.

Memoir No. 4. Geological Reconnaissance along the Line of the National Transcontinental Railway in Western Quebec; by W. J. WILSON. Pp. 56; 5 plates, 1 map.

No. 9–E. Bighorn Coal Basin, Alberta; by G. S. MALLOCH. Pp. 66; with one map.

No. 10. An Instrumental Survey of the Shorelines of the Extinct Lakes Algonquin and Nipissing in Southwestern Ontario; by J. W. GOLDTHWAIT. Pp. 57; 4 plates, 4 maps.

No. 11—T. Triangulation and Spirit Leveling of Vancouver Island, B. C., 1909; by R. H. CHAPMAN. Pp. 31, with one map.

No. 15—P. On a Trenton Echinoderm Fauna at Kirkfield, Ontario; by FRANK SPRINGER. Pp. 68; 5 plates, 3 figures.

No. 16—E. The Clay and Shale Deposits of Nova Scotia and Portions of New Brunswick; by HEINRICH RIES, assisted by JOSEPH KEELE. Pp. 155; 32 plates, 16 figures.

Also several geological maps of Lake Timiskaming, etc.

(2) In the MINES BRANCH, A. P. LOW, Deputy Minister, EUGENE HAANEL, Director, the following:

Summary Report of the Mines Branch for the calendar year ending December 31, 1910. Pp. ix, 243; 16 plates, 1 figure, 1 map.

Special Reports on the following: Gypsum Deposits of the Maritime Provinces; by WILLIAM F. JENNISON. Pp. 171, with 36 plates, 19 figures, and 3 maps.

On the Molybdenum Ores of Canada; by T. L. WALKER. Pp. 64, with 14 plates and 10 figures.

Western Portion of Torbrook Iron Ore Deposits, Nova Scotia; by HOWELLS FÉCHETTE. Pp. 13; 4 plates, 1 map.

Also Reports for 1910, by JOHN MCLEISH, Chief of the Division of Mineral Resources and Statistics. The Production of Cement, Lime, Clay Products, Stone, and other Structural Materials. Pp. 60. The Production of Iron and Steel. Pp. 38. The Production of Coal and Coke. Pp. 31. A General Summary of the Mineral Production of Canada during the calendar year 1910. Pp. 37. The total value of all products for 1910 is given as nearly 107 million dollars, having increased from 64 millions in 1900, 17 millions in 1890, and 10 millions in 1886.

8. *On the present distribution and origin of the calcareous concretions in coal seams, known as "coal balls";* by M. C. STOPES and D. M. S. WATSON. Phil. Trans. Royal Soc. London, Ser. B, vol. cc, pp. 167–218, pls. 17–19, 1907.—This very interesting paper shows conclusively that the coal balls found in thin coal beds of the "Lower Coal Measures" in Lancashire, Yorkshire and Cheshire, England, were formed *in situ.* The general conclusions of the authors are as follows:

"Groves of large trees with smaller herbs and ferns finding place between and around their stems grew in the flat swampy

levels between the higher ground and the sea. The water round their roots was brackish or salt, as is the water of the mangrove swamps to-day, and into its quiet pools and shallows twigs and branches, stems, leaves, and fruits fell or were blown. These fragments sank into the mass of *débris* already saturated and were there shut out from the atmosphere and preserved by the salt water in which they lay immersed. Parts of the plants decayed and thus liberated the organic carbon, which began its slow task of reducing the sulphates and depositing them as insoluble carbonates. This process continued long without the entry of impurities or the deposition of anything but plant remains, and the rootlets of the living plants wandered among the dead ones, finding their way even through the heart of their stems or seeds.

"All the time the land was slowly sinking, and when several feet of *débris* had accumulated the level sank more abruptly till the plants were well submerged and the place where the forest trees had lived was covered by the waters of an arm of the sea. Over them was deposited fine mud, with the shells of *Goniatites* and *Aviculopecten*, which lived and died in the waters. The plant masses below were continually withdrawing the sulphates of lime and magnesium from the sea water and depositing them as carbonates round the many centres started among the fragments of plants. The supply of salts was inexhaustible, for new water mingled continually with the old and brought fresh sources of mineral to petrify the plants. Thus in the heart of the masses of coal were formed large and small concretions of carbonate, some regular as balls and very large, others minute and uniting together to form wisps or sheets of stone lying in the coal.

* * * * * *

"In the sea above, the currents carried fragments of plants from the neighbouring land, brought by the streams from the higher ground. These sank in the muddy floor and were gradually crushed by the silt collecting above them, till they were flattened as impressions in the beds which afterwards formed shales * * *.

"These drifted plants, whether their fate was to be enclosed in the preserving nodules or to be crushed into the shales, had principally come from regions different from those which had produced the half-formed coal now lying immediately below them.

"Slowly they too were covered by the fine deposits which collected gently over them, until the sea bottom rose again to form a new land. All this time the plants were preserved in the coal balls without disturbance or hurt, and although the coal-forming *débris* had been pressed down into coal which was now but a foot in thickness, they remained uncrushed in their original form.

* * * * * *

"Thus, the 'coal balls' in the coal are the relics of a forest which grew quietly in the swamp in the place where they are now found, while the plants in the shales and in the roof nodules

above had drifted out to sea from other districts and bear in the character of their structures the impress of the different type of land on which they lived" (pp. 210, 212). C. S.

9. *The early Paleozoic Bryozoa of the Baltic Provinces;* by RAY S. BASSLER. U. S. Nat. Mus., Bull. 77, 1911, pp. 382, pls. 13 and 226 text illustrations.—This important work on the Ordovician Bryozoa of Esthonia and Sweden describes in detail 161 forms, and of these 69 are either new species or new varieties. All of these fossils are also carefully located in the geologic horizons, and as so many species are common to Europe and North America, this evidence furnishes the author with excellent faunal criteria for exact intercontinental stratigraphic correlation. On an average about 35 per cent (or a total of 65 out of 161) of the species are common to the Baltic area and America. On the basis of this evidence the author has the decided advantage of all previous stratigraphers and he makes out a good case, proving his detailed correlations, and also that the Ordovician sequence of Esthonia when compared with that of the interior of America is very incomplete. His main conclusion is "that the greater part of the Russian Ordovician section may be directly correlated with the Black River group of America, while the Upper Lyckholm and Borkholm limestones are the equivalents of the Richmond group" (2).

The author then takes up a short study of the Arctic American Ordovician faunas and finds "that the geologic section at Baffin Land consists of Black River strata resting upon the old crystalline rocks, followed by an early Trenton formation equal to the Stewartville and Prosser limestones of Minnesota, and this in turn succeeded [apparently] unconformably by the widespread coral zone of the Richmond group" (36). He has plotted on a paleogeographic map (43) all the known Arctic occurrences of Black River and early Trenton deposits, and brings out very clearly the striking new knowledge that the faunas entombed in these rocks are from the Arctic ocean and that its waters and life have spread at times during the Ordovician southward into northern Europe and into America as far as Tennessee. This distribution is now established and is further borne out by the similar spread of the Silurian faunas which Weller published many years ago showing that they too are also largely of Arctic and North European origin. C. S.

10. *A description of the fossil fish remains of the Cretaceous, Eocene, and Miocene formations of New Jersey;* by HENRY W. FOWLER. Geol. Surv. N. J., Bulletin 4, 1911, pp. 192, with 108 text figures.—This work is a descriptive and fully illustrated summary of the fish remains, essentially sharks and chimæras, found in the late Mesozoic and Tertiary deposits of New Jersey. Of species there are over 90 (sharks 43, chimæras 21, true fishes 24, uncertain 3), and of these but 4 are new forms. C. S.

11. *Types of Ore Deposits;* edited by H. FOSTER BAIN. Pp. 378, with 345 figures. San Francisco, 1911 (Mining and Scientific

Press).—This book is designed to present an accurate account of the present state of opinion regarding the genesis of ores. The different chapters have been written by men each of whom is an authority concerning the type of deposit that he describes. Many of the papers have appeared previously in various magazines, etc. The following list of chapter subjects with their authors is sufficient proof of the character and value of the volume: Introduction by H. Foster Bain ; The Clinton Type of Iron Ore Deposits by C. H. Smyth, Jr. ; The Lake Superior Type of Iron Ore Deposits by C. K. Leith ; Flats and Pitches of the Wisconsin Lead and Zinc District by H. Foster Bain ; Lead and Zinc Deposits of the Ozark Region by E. R. Buckley ; Native Copper Deposits by Alfred C. Lane ; Cobalt District, Ontario, by S. F. Emmons ; Geology at Treadwell Mines by Oscar F. Hershey ; The Saddle Reef by T. A. Rickard ; Contact Deposits by James F. Kemp ; The Conglomerates of the Witwatersrand by F. H. Hatch ; Replacement Orebodies and the Criteria by Means of which they may be Recognized by J. D. Irving; Outcrop of Orebodies by William H. Emmons; Some Causes of Ore-Shoots by R. A. F. Penrose, Jr. W. E. F.

12. *Brief Notices of some Recently Described Minerals.*—Muthmannite is a telluride of gold and silver from Nagyag in Transylvania. The mineral has been earlier called müllerine, gelberz and weistellur and by Schrauf was referred to krennerite (see Dana, Syst. Min., p. 104). Zambonini, however, makes it distinct with the formula (Ag, Au) Te ; this is based upon the following analysis by C. Gastaldi : Te 46·44 Au 22·90 Ag 26·36 Pb 2·58 = 98·28. The name is given in honor of W. Muthmann of Munich.—*Zeitschr. Kryst.*, xxix, 246, 1911.

Yttrofluorite is a fluoride of calcium and the yttrium earths described by Th. Vogt from a pegmatite in northern Norway. It resembles fluorite in form but shows only imperfect octahedral cleavage. The luster is vitreous ; the color yellow to brown or green ; hardness = 4·5 ; specific gravity 3·56. An analysis gave :

F	CaO	Y-earths	Ce-earths	alk.	ign.	
45·54	54·89	17·35	1·68	0·15	0·67	H_2O under 100°
						0·22 = 120·50, or deducting O 19·17 = 101·83.

Yttrofluorite is near yttrocerite but differs in its larger percentage of the yttrium-earths and practical absence of water.—*Centralbl. Min.*, 1911, 373.

Eichbergite is a sulphide of copper, iron, antimony and bismuth from the magnesite deposits of Eichberg in the Semmering, Austria ; it is described by O. Grosspietsch. It occurs in massive form with indistinct crystalline structure. The color is iron-gray; luster metallic ; hardness over 6 ; specific gravity 5·36. An analysis gave :

S	Bi	Sb	Cu	Fe
12·74	51·53	30·00	3·62	1·45 = 99·34

The calculated formula is $(Cu,Fe)_2S.3(Bi,Sb)_2S_3$.—*Centralbl. Min.*, x, 1911, 434.

FERMORITE is a new arsenate and phosphate of calcium and strontium described by G. F. Herbert Smith and G. T. Prior from the manganese-ore deposits of India. The mineral is apparently hexagonal in crystallization but occurs chiefly massive; it is pale pinkish white to white in color and translucent with a greasy luster. The hardness is 5, and the specific gravity 3·518. An analysis (Prior) gave:

As_2O_5	P_2O_5	CaO	SrO	F	H_2O	insol.
25·23	20·11	44·34	9·93	0·83	*tr.*	0·08 = 100·52

The formula deduced is analogous to that of apatite; written in the old form it is: $3[(Ca,Sr)_3(P,As)_2O_8] . Ca(OH,F)_2$. The locality is at Sitapar in the Chhindwara district, Central Provinces, India. It is named after Dr. L. Leigh Fermor of the Geological Survey of India. The manganese deposits of Kajlidongri in the Jhabna State have also afforded crystallized specimens of the rare mineral TELASITE.—*Min. Mag.*, xvi, 84, 86, 1911.

THORVEITITE is a silicate of certain rare elements (scandium 44 p. c., also yttrium, didymium, erbium, *et al.*) from the Iveland parish in the Sätersdal, Southern Norway; it is described by J. Schetelig and named after the discoverer, O. Thorveit. It occurs in orthorhombic crystals of simple habit, but uniformly twins. The prismatic cleavage (73° 25′) is distinct; the hardness is 6–7; the specific gravity 3·571; color grayish green with a luster inclining to adamantine. The mean of two analyses gave:

$$SiO_2\ 42·86,\ R_2O_3\ 57·67,\ \text{ign.}\ 0·44 = 100·97$$

The prominent rare elements present are named above; their molecular weight is 157·1.

CHROMITITE is a supposed new chromium mineral to which the formula $Fe_2O_3.Cr_2O_3$ is assigned. It is described by M. Z. Zovitschitsch as derived from sands washed down from Mt. Zeljin in Servia. It occurs in brilliant octahedral crystals which are feebly magnetic and have a specific gravity of 3·1; they are insoluble in mineral acids.—*Sitzungsber. Akad. Wien*, cxvii (IIb), p. 813, in *Zs. Kryst.*, l, 83.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Fourth Report of the Wellcome Tropical Research Laboratories*, at the Gordon Memorial College, Khartoum; Vol. A. Medical, ANDREW BALFOUR, Director. Pp. 404, with numerous illustrations, including 14 colored plates. Department of Education, Sudan Government, Khartoum, 1911.—The Wellcome Research Laboratories at Khartoum were founded in 1903 for the investigation of problems connected with the development of the Sudan. Of primary importance is the study of the conditions of hygiene and sanitation, and the nature of the diseases affecting the people and animals, especially the communicable diseases. A

secondary object is the study of the fungi and insects injurious to the crops and animals, the analysis of foods, water, minerals, ores and fuels, and all such other matters as pertain to the economic development of the natural resources of the country.

The first of these aspects—the medical—is treated in the beautifully illustrated quarto volume in hand, while the second aspect —General Science—will be represented by a similar volume shortly to be published.

The present book consists of some forty separate, but related, papers dealing with the general matters of tropical hygiene and blood examination, with special reports on the recent discoveries relating to the diagnosis and treatment of particular diseases. Especial attention has been given to the means of identification and the study of the life cycles of the parasites involved, and many new and important facts have been discovered. The volume also includes special reports by the Sleeping Sickness and Kala-azar Commissions.

The results of the work of the laboratories up to the year 1908 have been published in four quarto volumes, and the fact that the important researches described in the present report have been accomplished during the past three years emphasizes the remarkable industry of a corps of workers under climatic and other conditions that would seem far from ideal for the most concentrated effort. W. R. C.

2. *Einführung in die Mykologie der Nahrungsmittelgewerbe;* von Dr. ALEXANDER KOSSOWICZ. Pp. viii, 138; 5 plates, 21 text figures. Berlin, 1911 (Gebrüder Borntraeger).

Einführung in die Mykologie der Genussmittel und in die Gärungsphysiologie; von Dr. A. KOSSOWICZ. Pp. viii, 211; 2 plates, 50 text figures. Berlin, 1911 (Gebrüder Borntraeger). The present "pure food movement" and the increased interest in the problems of the preparation and preservation of foods have encouraged the publication of books bearing on these topics, in a form which shall not be too technical for others than the extreme specialist. One of the Kossowicz monographs reviews the nature of the microflora of various familiar products—milk and its derivatives, meat, eggs, and fruits—together with suggestions respecting the preservation of them. The second deals with the microbiology of the fermentation industries, the manufacture of vinegar and mustard, tobacco fermentation, and the biological factors involved in the preparation of coffee, tea, cocoa and vanilla for the market. Though unembarrassed by extreme details, the subject matter is obviously intended for individuals possessed of some scientific and technical training rather than for the layman. An extensive bibliography is included in each volume. L. B. M.

3. *Principles of Human Nutrition. A Study in Practical Dietetics;* by WHITMAN H. JORDAN, Director of the New York Agricultural Experiment Station. Pp. xxi, 450. New York, 1912 (The Macmillan Company).—The book is intended to

supply a rational basis for practical dietetics. With this end in view the entire field of the nutritive phenomena—digestion, absorption, metabolism—is reviewed in relation to the anatomical parts of the body and physiological processes involved. The chemical nature of the foodstuffs and the transformation which they experience prior to their utilization by the organization are discussed. From the popular standpoint—and to this the volume is especially intended to contribute—the applications of the scientific facts to correct dietary habits are presented in a form acceptable to those with limited scientific training. There are many elements of novelty, various unique view-points, and evidences of the up-to-date character of the compilation everywhere. The addendum of analyses of American food materials gives an added practical value to the volume. L. B. M.

4. *Ostwald's Klassiker der exacten Wissenschaften.* Leipzig, 1911 (Wilhelm Engelmann).—The following are recent additions to this valuable series of scientific classics :

No. 181. Méchain und Delambre : Grundlagen des dezimalen metrischen Systems oder Messung des Meridianbogens zwischen Breiten von Dünkirchen und Barcelona.

Borda und Cassini : Versuche über die Länge des Sekundenpendels in Paris. In Auswahl übersetzt und herausgegeben ; von Dr. Walter Block. Pp. 200.

No. 182. Vollständigere Theorie der Maschinen, die durch Reaktion des Wassers in Bewegung versetzt werden ; von L. Euler. Herausgegeben von Ernest A. Brauer und M. Winkelmann. Pp. 94.

Obituary.

Professor George Jarvis Brush, an assistant editor of this Journal from 1863 to 1879, died at his home in New Haven on February 6 in his eighty-first year. He was appointed Professor of Mineralogy in the Sheffield Scientific School of Yale University in 1864, and became Director of the School in 1872. In 1898 he retired from active service but remained President of the Sheffield Trustees until his death. A notice of Professor Brush is deferred until a later number.

Sir Joseph Lister, famous for his discovery of the antiseptic treatment in surgery, died in London on February 11 at the age of eighty-five years. He served as Professor of Surgery in Glasgow and Edinburgh Universities, and in King's College, London.

Charles Gilbert Wheeler, the chemist and mining geologist, died on January 30 at the age of seventy-five years.

Mr. J. B. Edouard Bornet, the eminent French phycologist, died at Paris on December 18, at the age of eighty-three years.

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THE

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FOURTH SERIES

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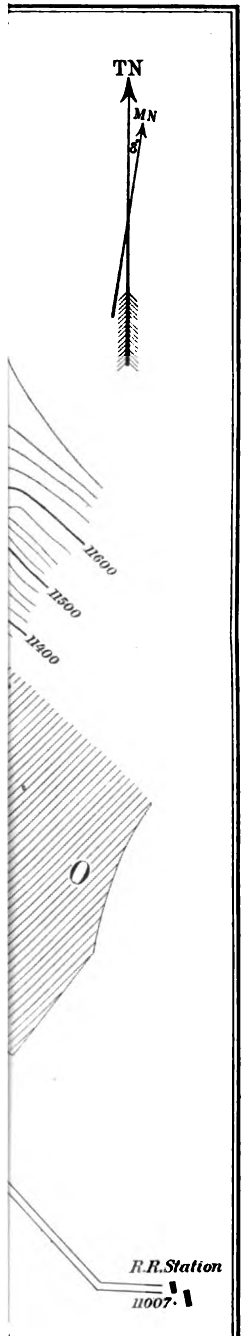


THE

ERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

:. XXVI.—*The Discovery of Pre-Historic Human Remains near Cuzco, Peru*; by HIRAM BINGHAM, Director of the Yale Peruvian Expedition. (With Plates I and II.)

THE Yale Peruvian Expedition was organized to do archæological, geographical, geological, and topographical reconnaisance. We spent the first part of July, 1911, in and about Cuzco. On the morning of July 6, while walking up a gulch called *Ayahuaycco quebrada* west of Cuzco (fig. 1), in company with Professor Harry W. Foote, the collector-naturalist of the Expedition, and Dr. William G. Erving, our surgeon, I noticed a few bones and several pieces of pottery interstratified with the gravel bank of the gulch and apparently exposed by recent erosion. This led me to examine both sides of the gulch very carefully. A hundred yards above the point where the first bones were noticed we found that erosion had cut through an ancient ash-heap containing a large number of fragments of bones and pottery. Still farther up the gulch and on the side toward Cuzco I discovered a section of stone wall built of roughly finished stones more or less carefully fitted together (fig. 2). At first sight this wall appeared to have been built to prevent further washing away of that side of the gulch. Then I noticed that above the wall and flush with its surface the bank appeared to consist of stratified material, indicating that perhaps the wall antedated the gravel deposits.

Fifty feet up the quebrada another portion of wall appeared. Between this and the section first seen the gravel bank somewhat protruded. On top of the bank was a cultivated field. In order to see whether the wall extended behind this gravel bank, under the field, and whether the two portions were continuous, I excavated and found, after half an hour's work on the compact gravel, that there was more wall behind the

FIG. 1.

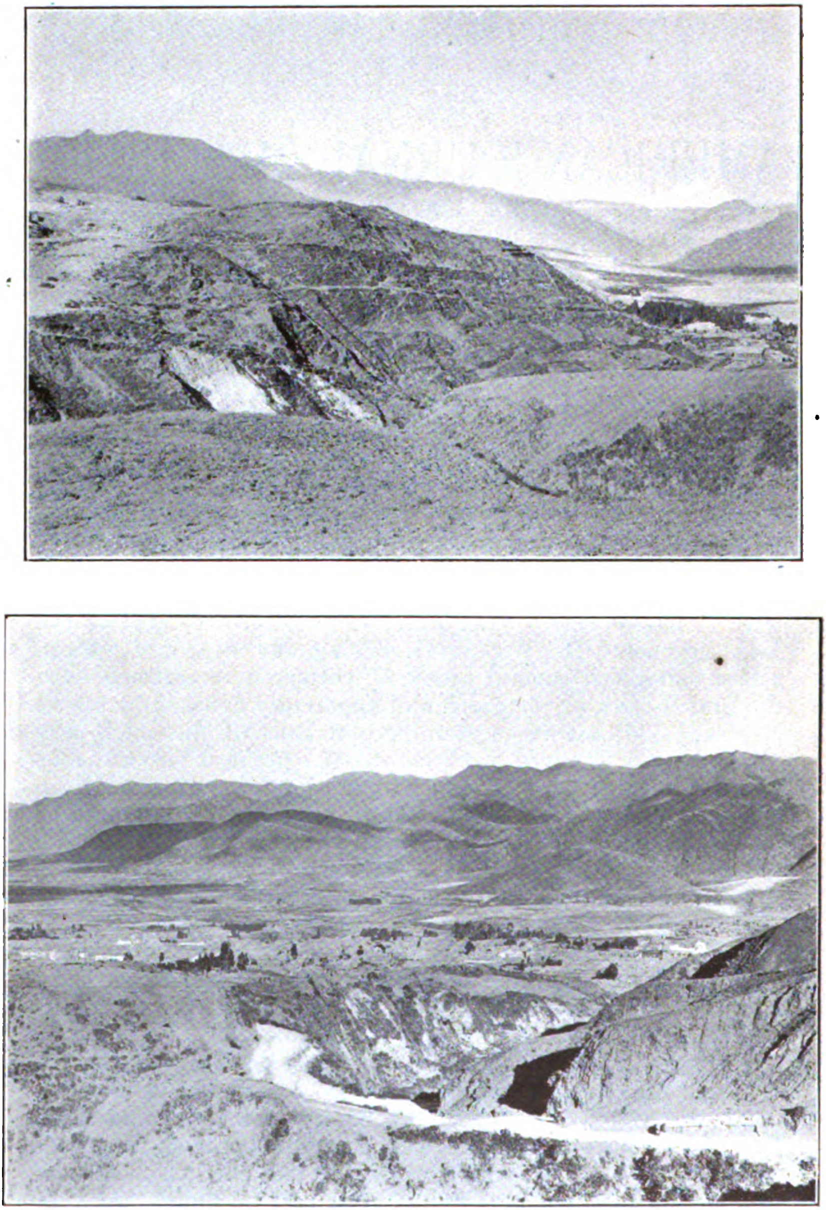


FIG. 1. The Cuzco Valley. The upper photograph shows the Sacsahuaman fortress and is panoramic with the left border of the lower photograph, which shows the Ayahuaycco quebrada.

stratified sides of the gulch (fig. 3). The Prefect of Cuzco later helped me to secure the services of six Indians, with whose aid we cut through the wall and found it was about three feet

FIG. 2.

FIG. 2. Stratified gravel overlying a buried wall in Ayahuaycco quebrada.

thick and nine feet in height, carefully faced on both sides and filled in with rubble. As this type of stonework is not uncommon in the foundations of some of the older buildings in the western part of the city of Cuzco, and as it is usually called by

the inhabitants Incaic, I was at once struck by the idea that this kind of wall must be very much older than we should be led to suppose by our present ideas of Inca civilization. Such a thesis would be necessary to account for a wall completely covered over to a depth of six or eight feet by a compact gravel bank, a bank later eroded to a depth of ten feet. Further investigation in this part of the gulch revealed numbers of potsherds and bones.

Fig. 3.

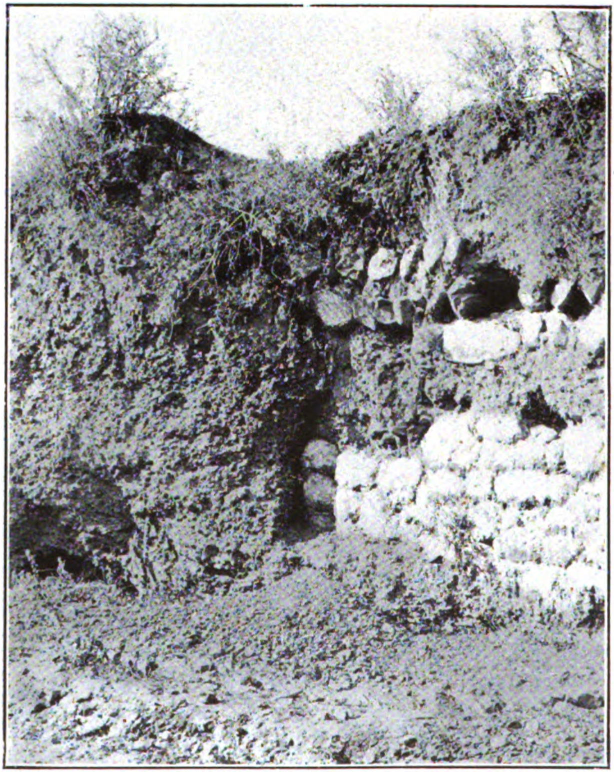


Fig. 3. Portion of buried wall after partial excavation.

A few days later I followed the *Ayahuaycco quebrada* up to its head, using a road on its east side. In various places I was struck by evidences of ancient civilization. Ash-heaps, recent and ancient, a stone-paved area which may have been a threshing floor or market place, and numbers of bones and

FIG. 4.

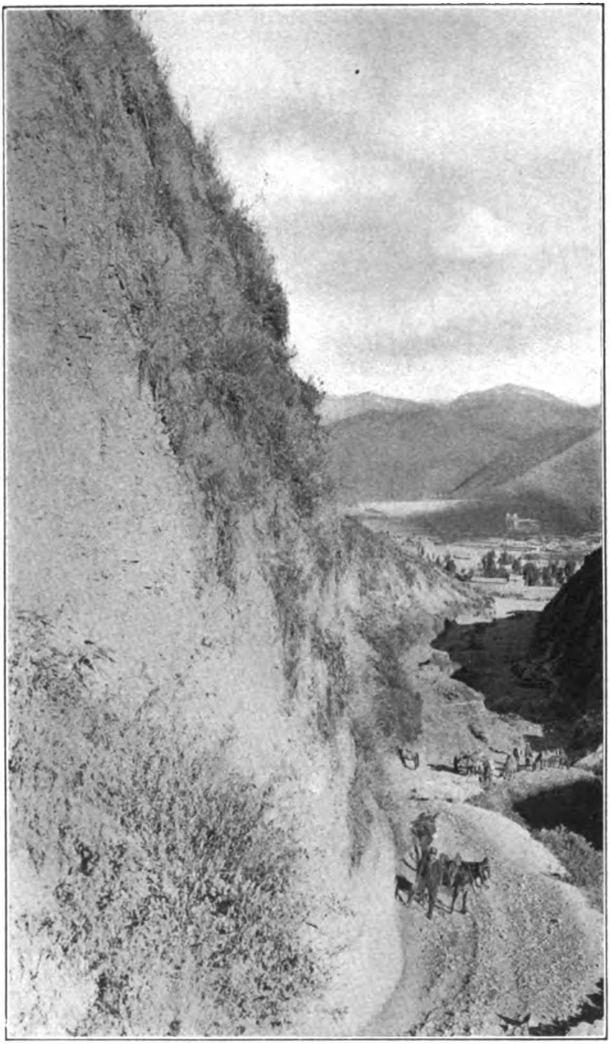


FIG. 4. Ayahuaycco quebrada. Profile view of bluff in which vertebrate remains were found. Cuzco in the middle distance. The man in the foreground is standing in front of the excavation.

potsherds offered a most interesting field for speculation and study. Ayahuaycco means "the cadaver quebrada" or "dead man's gulch," or "the valley of dead bodies." There is a

tradition that this valley was once used as a burial place for plague victims in Cuzco, possibly not more than three genera-

FIG. 5.

FIG. 5. The bone locality before excavation. The projecting femur first discovered lies directly beneath the hammer. Note the stratification from a point about one foot above the bone down to the base of the bluff.

tions ago. Such a story appears to be well borne out by the great number of human bones that occur in the talus slopes. I was most anxious to see whether anything could be found definitely *in situ*, where the stratification had not been disturbed.

After proceeding up the valley for more than half a mile it narrowed and the east side, along which I was walking, became very precipitous (fig. 4). The road had apparently recently been widened and this made the bank at this place practically perpendicular. About five feet above the road I saw what at first looked like one of the small rocks which are freely interspersed throughout the compact gravel of this region. Something about it led me to examine it more closely, and I then recognized that it was apparently the end of a human bone, probably a femur (fig. 5).

Fig. 6.

Fig. 6. The vertebrate remains after partial excavation. The photograph shows the long narrow lense of vertebrate material and the jumbled state of the bones. The fallen end of the femur, in the lower left-hand corner, was originally in the stratum which the other bones occupied.

I was at once so impressed by the possibilities, in case it should turn out to be true that this was a human bone and had been buried centuries ago under seventy-five or a hundred feet of gravel, that I refrained from disturbing the bone until I could get the geologist and the naturalist of the Expedition to witness its excavation. Professor Isaiah Bowman, who had already made studies in the Central Andes, and was the geologist-geographer of the Expedition, was at this time only a few days away making a preliminary study of the Anta basin. On his return to Cuzco Professor Bowman was requested to make a physiographic study of the gulch in which the human remains had been found. The results of his study are presented in a

FIG. 7.

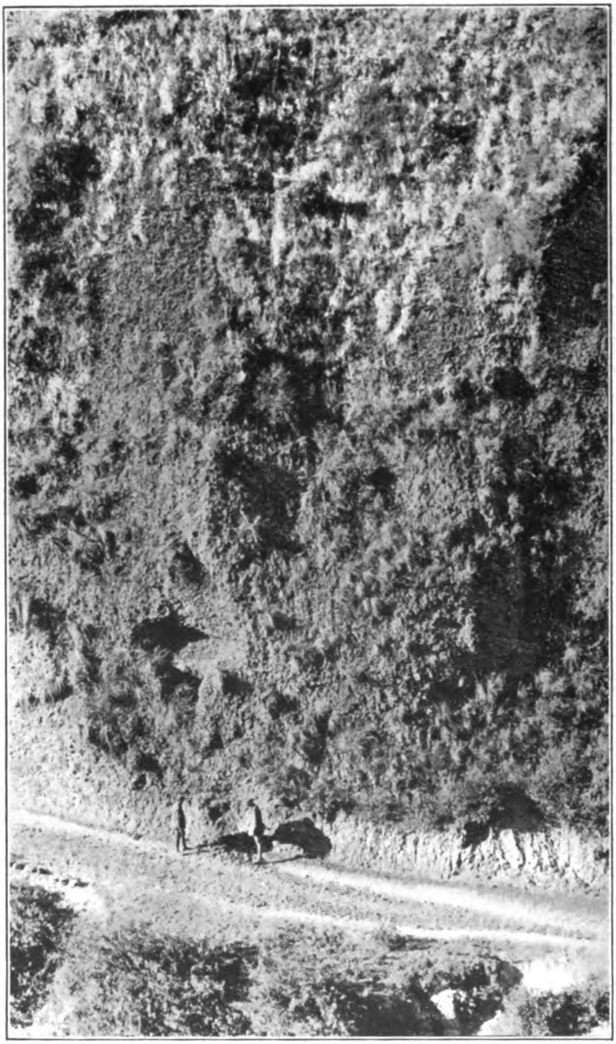


FIG. 7. Looking squarely at the face of the bluff. The bones were collected from the excavation between the men at the foot of the hill.

separate article following this. Our topographer, Mr. Kai Hendriksen, made a detailed map of the gulch and a rough

sketch map of the vicinity of Cuzco, showing the relation of the gulch to the well-known ruins in the neighborhood. These maps are also included in the present number (Plates I and II).

On the afternoon of July 11 Professor Bowman and I excavated the femur and found behind it fragments of a number of other bones. These we took out as carefully as possible. They were excessively fragile. The femur was unable to support four inches of its own weight, and after that much had been excavated the exposed end fell off (fig. 6). The gravel was somewhat damp but could hardly be called moist. The bones were dry and powdery. It is difficult to describe their color. Perhaps "ashy grey" is as near as anything. The end of the femur, first seen, was so like the pebbles as to be distinguished from them only with the greatest difficulty.

Professor Foote was asked to photograph the wall, portions of the gulch, and the location of the bones, before, during and after the process of excavation. The accompanying illustrations were nearly all taken by him (fig. 7).

The bones were carried to our hotel, where they were again photographed, soaked in melted vaseline and then packed in cotton batting. On my return to the States in December, the bones were submitted to Dr. George F. Eaton, curator of osteology in the Peabody Museum, for examination. His report is also presented herewith (p. 325).

It was a keen disappointment that we were not able to spend more time in Cuzco. Notwithstanding my great interest in these prehistoric human remains, I felt that it was wiser to carry out the plans originally adopted for the Expedition, although that meant a hurried departure from Cuzco without doing more than is shown by the results presented herewith. It seems to me extremely desirable to continue the work of exploration and excavation in and about Cuzco, for it is highly probable that important data bearing on Inca and pre-Inca civilization may be obtained here.

EXPLANATION OF PLATES.

PLATE I. *Cuzco and Environs.*

a: The Cathedral. *b*: La Compania. *c*: La Merced. *d*: San Francisco. *e*: Santa Clara. *f*: Hospital. *g*: Santa Ana. *h*: Santo Domingo. Intersection of arrows in upper left hand corner indicates location of bone deposit in Ayahuaycco Quebrada. Altitudes based on railroad survey. Contour interval 20 ft. Shaded area: present limits of the city of Cuzco.

PLATE II. *Ayahuaycco Quebrada.*

BM 1: Bench mark about 100 ft. west of excavation where human and other bones were found on roadside at base of high bluff. BM 5: Bench mark near talus slopes, containing many bones and potsherds. BM 6: Paved area. BM 7: Recent ash heaps. BM 8–9–10: Location of buried wall. WT: Water tank. *g*: Santa Ana church.

ART. XXVII.—(Part II) *The Geologic Relations of the Cuzco Remains;** by ISAIAH BOWMAN.

HISTORIC Cuzco lies at the head of one of the most beautiful intermontane valley-basins in the Central Andes. The broad flat basin floor is deeply cloaked with land waste which also extends well up the bordering slopes and the tributary valleys. High mountains rim about the basin like a gigantic wall and their slopes in a few places lead up to summits snow-covered during the southern winter. The upper grass-covered slopes are the home of mountain shepherds who find in the otherwise unoccupied lands of their bleak territory ample room for their flocks and herds. Upon the lower slopes of the mountains the agricultural Indian breaks a tough sod here and there and plants his chief vegetable, the potato. Farther down, on the fringe of alluvium, are grain fields, potato patches, and bright green alfalfa meadows—almost all irrigated land, intensively cultivated, and supporting a dense population.

The Cuzco basin (fig. 1) is about fifteen miles long. Its width varies from a few hundred yards at the narrow lower outlet of the basin to several miles a little below Cuzco. The floor of the basin is from 11,000 to 11,500 feet above sea level. Dozens of small streams rising in the surrounding highlands follow steep irregular courses and furnish water to the irrigation ditches. Among these the Huatanay and the Tulumayu are the most important. All of these streams bear down quantities of land waste (now much less than formerly) and all have dissected the marginal belt of alluvium and even the alluvial floor of the basin, which they formerly built up. Therefore at some time in the recent geologic past the streams of the basin have changed from aggrading to degrading agents.

It is in one of the ravines cut into the bordering alluvium that the gravel deposits are exposed in which the Cuzco man was found.† The present city extends up to the mouth of the ravine as shown in fig. 4. The lower ravine appears to have been occupied by man for a long time. Several feet from the surface and interstratified with the surface material are artificial beds of wood ashes alternating with thin yellowish-brown layers of sand and gravel. It appears that when the present slopes were being fashioned, and before erosion had gashed the alluvium, man inhabited the region and that he has witnessed

* I am indebted to Professors Schuchert, Gregory, Barrell, Lull, and MacCurdy, for criticisms.

† For an account of the discovery by Professor Bingham see the preceding paper.

the change from an aggrading to a degrading surface. A buried wall, the subject of another paper,* points in the same direction. Far up the slopes of uninhabited though still cultivated spurs one may find these ash beds, and mingled with them are bones of many kinds, shells, charred corn and quiña, and bits of broken pottery. Though the relations of this sort of material to the surface in every place indicate that man has long been an inhabitant of the region, no antiquity can be claimed for any of that examined during the work of the present expedition, for it all lies buried in but five or six feet of material. It is, however, equally well stratified and shows that the earliest ash and charcoal material was accumulated while alluviation was still going on. This should not, however, be confused with the strong alluviation of the glacial period. The ash material is interstratified with lower, younger, and thinner alluvium whose lowermost layers may be not more than a few thousand years old.

Evidences of man's existence in the Central Andes in late glacial or early post-glacial time were reported by the writer several years ago.† From the position of certain abandoned trails and ruined corrals in the Huasco basin and from the nature of associated strand lines and terraces, it is certain that man lived in the region in early times and that he was contemporaneous with a large lake where there are at present only a few scattered ponds and marshes. We have now from the Cuzco basin the actual remains of man found embedded in gravels of still earlier date. The following paragraphs deal with the geologic and geographic character of the gravel beds in point. If their age can be fixed we shall also be able to tell the age of the remains interstratified with them.

Summary of Results.

A brief summary of the chief features of the case will serve to guide the reader in his interpretation of the details of the problem.

The bones found near Cuzco were contemporaneous with the compact gravels in which they were embedded. They were disposed in the form of a lense about 10 feet long and 6 inches thick. From (1) their disposition with respect to each other, (2) their relations with the bedding planes, and (3) their worn condition, it is concluded that they were interstratified with the gravel beds. The age of the beds thus becomes the critical factor in the interpretation. From a detailed study of the

* A buried wall at Cuzco: Its climatic significance and its relations to the question of a Pre-Inca Race.

† Isaiah Bowman, Man and Climatic Change in South America, Geog. Journ. (London), March, 1909, pp. 268-278.

geology of the upper Cuzco basin with special reference to glacial forms, it is concluded (1) that the beds belong to a glacial series, (2) that the bones were deposited during a period of pronounced alluviation, and (3) that since the deposition of the bones from 75 to 150 feet of gravel were deposited over them and later partly eroded. The age of the vertebrate remains may be provisionally estimated at 20,000 to 40,000 years.

The weaknesses of the case lie in the following facts: (1) Certain vertebrate remains* found associated with the human bones may be referred to bison, but they are not sharply differentiated from the bones of modern cattle. Bison remains have not been found either in other places in the Central Andes or elsewhere in South America. The distinctions between these fragmentary bones and those of modern cattle are not sufficiently well-marked to enable one to say absolutely that they could not be bones of domesticated cattle. Furthermore, certain canine bones gathered in connection with the human remains cannot be said to be unlike those of the modern domesticated dog. While both these pieces of evidence are negative in character and do not actually disprove the case, they raise wholesome doubts that can not be dispelled save by further field work, especially excavation. (2) In the second place, there is one untested possibility and until that test is applied the case cannot be said to be proved absolutely. It is within the limits of possibility, although it still seems very unlikely, that the bluff in which the bones were found may be faced by younger gravel and that the bones were found in a gravel veneer deposited during later periods of partial valley filling. Until excavation is carried on, the interpretation must rest, not upon all the facts, as X, but upon X-1 facts. Indeed excavation may show that the facts in hand are really X-2 or X-3 in number.

Criteria.

In determining the age of buried human remains account must be taken of two guiding principles:

(1) The remains and the beds in which they are found must be proved to be contemporaneous.

(2) The age of the beds must be determined by independent means.

The possibility of landslips, of recent changes in the behavior of streams, and of burial by human hands or by animals, must be considered in minutest detail. This is forced

* For both the nature of the vertebrate material and the characteristics of the individual bones see the report by Dr. George F. Eaton in this number of the Journal (p. 325).

upon one not only by the rigid demands of scientific method but also because failure to collect and interpret all data bearing on the problem may lead to unsatisfactory conclusions and has in fact cast doubt on the authenticity of one after another of the reported discoveries of human remains. It is, therefore, essential that the structure and composition of the deposits, the conditions of burial, and the physiographic history of the region be discussed in detail.

If human remains were common in hard rock of Tertiary or Cretaceous age the case would be quite different. The indurated rock would show such clear signs of disturbance in case of burial as to leave no one in doubt; the lapse of time after deposition would be so great that a certain degree of fossilization would have resulted; morphological differences between the buried bones and the bones of existing forms would be distinguishable; associated fossils would supply collateral evidence as to age. But in America the conditions are far from this ideal. Human remains are always reported from loose surface material; if the material is gravel the question of stratification arises; even if the remains are interstratified they show no prominent variations from existing types; and in almost all cases no other fossils accompany the remains to throw light upon their geologic relations.

Interstratification of Bones and Gravel.

The coarse gravels in which the Cuzco man was found are rudely stratified in places; in other places they are very markedly stratified. The stratification at the precise locality where the bones lay was coarse though the pebbles range in size from a pea to a walnut and are mixed with ordinary yellow quartz sand. The bones themselves formed part of a stratum of slightly finer material, and occurred in the form of a layer about ten feet long and six inches thick (fig. 6). Stratification within the limits of the six-inch layer was observed. It shows clearly in the photograph, fig. 5.

Not only were the gravels about and within the six-inch layer disposed in a stratified manner but the bones themselves were in positions signifying natural deposition by water rather than artificial deposition through human burial. With reference to a vertical plane they lay in a jumbled state; all were essentially flat with reference to a horizontal plane. One rib lay at the extreme right end of the ten-foot limit, another at the extreme left. Mixed with the human remains were bones of a bison, a wolf, and a llama. There can be no question of the plain facts in the case as regards interstratification.

We must now consider the possibility of landslip. A block of gravel may slide by slow degrees from the top of a bluff and come to rest at the foot with stratification intact and with a dip in conformity with that of the beds in the undisturbed parent mass. In such a case it is evident that (1) between the disturbed and the undisturbed masses a break will occur and (2) both the material and the thickness and alternation of the beds will show marked contrasts on the two sides of the break. Now the bluff in which the Cuzco man was found is to some extent ravined and broken by landslips. East of the locality a series of small slips extend down valley for several hundred feet with characteristics quite unlike the undisturbed condition of the lense containing the bones. The line of separation between them and the parent mass is everywhere ragged with both horizontal and vertical variations. Material has been dragged down from an upper surface and is exposed to view near the bottom of the ravine. Such material exhibits recent unfossilized shells, even human bones and pieces of broken pottery, carbonized wood and corn, and the ashes of old and long-abandoned hearths or camp fires.

No one who sees these clear evidences of the displacement of material by landslips can fail to see the necessity for giving the mass containing the human remains the most rigid examination. At first sight the immediate surroundings indeed suggest a landslip. Immediately above the stratum containing the bones was a break in the face of the bluff about four feet long (fig. 5). It rose in a curved line about two feet above the layer in which the bones were disposed and suggested the upper part of a grave, especially as the break exhibited a mould of organic material. After the excavation work was done, as much care was exercised in the examination of this break as in the gathering of the bones. Upon excavation of the gravel along the line of the break and forward from it two facts were discovered: (1) the break extended downward but a few inches and merged into hard undisturbed material in which the bedding planes ran apparently without interruption from within the main gravel mass to the outer edge of the bluff; (2) the mould consisted principally of a fungous growth mixed with a few species of lichens.

At first the mould-covered material seemed quite out of harmony with the undisturbed structure of the gravel beneath it, but when a larger area of bluff face had been examined a clear explanation was afforded quite apart from the idea of a grave. Anywhere along the faces of these gravel bluffs one may find the same material disposed in the same way. The break afforded an opportunity for the display of the mould but was in no way related to it. Upon the outermost surface of

the bluff was an earthy coating deposited from the clouds of dust raised by the feet of passing flocks and caravans. The same gray-yellow appearance is exhibited upon all surfaces not recently eroded. Upon removing the thin surface of such a bluff one comes upon what might be called an under surface somewhat like the under layer of skin on the human body and upon or in this are countless hosts of fungi. Their branching filaments or hyphae ramify through every pore; by scraping away the surface carefully one may exhibit a great area of fungous-covered gravel. Beyond the outer film of material

Fig. 8.

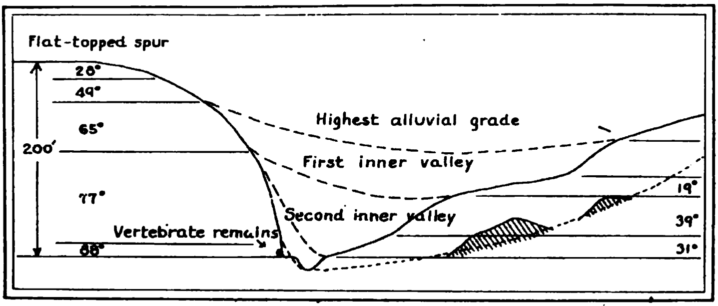


Fig. 8.* Topographic profile of ravine in which the vertebrate remains were found. Compare with figs. 1, 4, 7, and 9. Scale: 1 inch = 200 feet, vertical and horizontal. Shaded area represents bed rock exposed in tributary ravine. Degrees indicate declivity of ravine slopes at different elevations.

one comes in turn upon the yellow unmodified gravel free from dust and fungi. The linear distance from the face of the bluff to the undisturbed material is never more than two or three inches and generally but a half inch to an inch.

The structure of the main mass of material in which the bones were deposited may be observed in a ravine but fifty feet west of the bone locality. The unbroken character of the mass, its stratified condition, the fact that it lies as it was deposited with moderate inclination of the material down-valley, its smooth upper surface (fig. 1), its compact condition, the entire absence of recent material within the body of the gravel,—all these are features easy of observation and about which it would seem there could never be any question either as regards the facts or their interpretation.

Across the ravine from the bone locality a tributary gully extends far into the undisturbed gravels (fig. 9); the coarseness of the material, its degree of stratification, and its angle

* For figures 1–7 inclusive see preceding article.

[illegible] characteristics of [illegible]

Fig. [illegible]

Fig. [illegible] complementary [illegible] fig. 4. The [illegible]

[illegible] covered [illegible]

The progressive deflection of the stream [illegible] the north as shown in Figs. 4 and [illegible] has given [illegible] a very steep [illegible] climate [illegible] such a [illegible] vertical [illegible] retracting

the road seen in fig. 4. From the nature of the road-bed and the bluff it is inferred that the bluff originally had a profile represented by the broken line of fig. 8 (left, bottom). The construction of the road, therefore, further steepened a naturally steep bluff and carried the face of it back far enough to expose one end of a buried bone. It is possible that in building the road other associated bones were excavated and lost; also that much more material of a similar nature might still be found. Further excavation was impossible, however, because of other problems and because of the desire to leave the bluff (at least for the present) relatively undisturbed, so that interested students might see it almost in its original condition.

Physiographic Determinations.

When the geologic history of comparatively fresh deposits is desired, the application of physiographic principles is indispensable. Fossils may be wholly absent, or if present may be so closely related to the existing fauna and flora as to be of little value. In the present case we have to determine, first, a problem in structural geology—whether or not the bones occurred interstratified in deposits in place; and, second, and more important, the age of the deposits as determined (1) by the topographic forms developed on them and (2) by their geographic relations. The facts of structure are in this case relatively simple. The physiographic facts and relations are much more complex, though it is believed that they are no less substantial and convincing.

That the reader may have a proper guide in the examination of the evidence, I shall at once present the conclusions that the facts in the succeeding paragraphs seem to establish:

1. The deposits in which the vertebrate remains were found have the same age as deposits of similar composition and topographic relations all about the borders of the Cuzco basin.
2. The deposits belong to the glacial series; and to the latter of two main groups.
3. They were formed in a time of glaciation on the surrounding highlands and of alluviation in the valleys.
4. Since the burial of the Cuzco man thick bodies of gravel were deposited, and later eroded.
5. Since the deep erosion of the gravels there have been two minor periods of alluviation.
6. The gravels of glacial derivation rest upon (a) deformed and eroded sedimentary rocks of Tertiary and Paleozoic age and (b) igneous rock of pre-Tertiary age.

The principal geologic and physiographic relations are shown in fig. 10. The higher summits and intermediate slopes are

developed upon pre-Tertiary rock. Tertiary strata underlie the benchland of the middle distance and appear as alternating light and dark bands in fig. 13. Upon the Tertiary shales, clays, and sandstones are the glacial gravels and sands. They consist of a finer, older series, overlaid by a coarser, younger series; and both are now in process of dissection. Not only

FIG. 10.

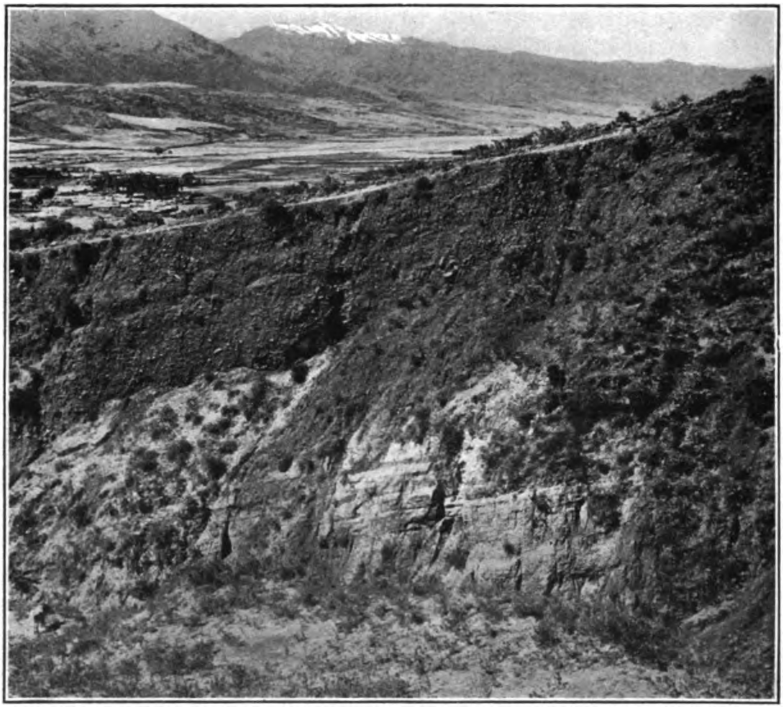


FIG. 10. Distant snow-capped mountains, part of Cuzco Valley in middle distance, and two series of glacial deposits, with unconformable relations, in the foreground.

the differences of composition, but also the line of separation between the two series of gravels may be clearly seen in fig. 10.

The glacial gravels of the Cuzco basin occur on all of the lower and most of the higher valley slopes and floors. They lie upon older eroded rock and are themselves being eroded at a rapid rate to-day no matter what their position. It follows that they represent a period in which erosion was halted upon all those slopes and on the floors of all those valleys on which

they lie. They could not have been formed under present conditions, for they are being eroded by the existing streams. They were formed during a time when waste was being shed from all of the higher valley heads and mountain slopes and collected principally on the lower slopes. Wherever the gravel deposits are traced into the higher valleys they may be seen to interlock or interfinger with glacial deposits—actual moraines or irregular masses of unstratified material. The interlocking relation is observable at a number of points in the Cuzco basin and is, besides, one of the most common relations throughout the Central Andes. I have studied similar cases all the way from southern Bolivia to central Peru. Furthermore, the condition is widely encountered in other continents: it has been noted in both North America and Europe under such a variety of topographic relations that its meaning is one of the clearest in physiographic geology. It would require no further emphasis were it not for the great importance attaching to it in the present instance.

It is characteristic of glacial gravels and sands that they occur in many valleys whose heads were not occupied by the ice. Among this class are the deposits in the ravine in which the human remains were found. It is inferred, however, that they have the same age as those which exhibit an interlocking relation in adjacent valleys. This appears at first sight to border so closely on mere analogy, that particular attention should be directed to the following argument for their age.

Starting at the glaciated head of any of the higher valleys of the Cuzco basin, one passes down over the morainic deposits to the more regularly distributed and stratified alluvium of the middle and lower sections of the valley. At the valley mouths one looks out upon a great belt of alluvium fringing the lower slopes and appearing to extend tongue-like up all the tributary valleys. The plane of the surface on which one stands is coincident with that of the surface of the adjacent deposits. There is lack of continuity only where some more massive or some longer spur extends far out into the basin, though such breaks are rare. One can find no marked differences between the deposits of the unglaciated and the glaciated valleys. In all cases the material is coarse, in all cases it leads to upper rocky slopes stripped bare of waste: the upper surfaces of the deposits of both the glaciated and the unglaciated valleys fall into a common plane: both have the same geographic position: along their common border, the deposits interlock in as clear a manner as do the glacial and alluvial material at the glaciated valley heads: both classes are benched, showing that there has been at least one important halt in the cutting down of the deposits since their formation. These are not accidental con-

cordances; for they would imply a repetition of accidents of both *time* and *place*. There are, to be sure, certain differences between the deposits, but they are differences of detail. The deposits at the mouths of the larger valleys are thicker; while both classes are coarse, those from the glaciated valley heads are coarser; though both classes are eroded and are being eroded, the thicker deposits are eroded to a greater depth, though as a rule at a higher absolute elevation. The principal characteristics of the belt of alluvium are brought out in figs. 1 and 10.

That the deposits of these two classes are contemporaneous points conclusively to some climatic condition which affected both alike, whether or not that condition led, as in some cases, to glaciation. It is inferred from the former extension of glacial systems that the climate of the Pleistocene was colder: it has not always been necessary from the conditions of a given place also to postulate greater precipitation, though such a postulate is imperative in many cases, including the one under consideration. The basis for the inference is relatively simple. Before the Pleistocene, waste supply and waste removal maintained a certain balance whereby large quantities of waste clung to the upper slopes, while another part of the waste was transported down valley without important aggradation. With the advent of the Pleistocene, waste was shed more rapidly from the upper slopes than it could be removed from the lower slopes and a fringe of alluvium was formed. That this should result in valleys whose heads were unglaciated means that a greater amount of water and snow (water by later periodic melting) fell on these valleys, and if on these valleys on all valleys tributary to the basin.

The conditions governing the actual formation of glaciers on the mountains about Cuzco are relatively few in number. Glaciers formed (1) in those valleys that reached above 12,500 feet, (2) in valleys with headwater tributaries able to supply important masses of snow or ice. Fig. 11 represents a glaciated valley at 13,000 feet. It has an extensive system of tributary slopes and minor valleys extending up to summits above 14,000 feet, where snow now collects in important amounts during the southern winter. Neighboring unglaciated valleys have few contributing slopes and a lower summit altitude.

The topographic characters of the glaciated portions of the valleys about Cuzco are strongly marked. Glacial striæ occur, though these are relatively few in number since the rock in so many instances is soft and upon exposure to weathering the striæ are soon destroyed. The lowest marks of glaciation are at 12,250 feet (aneroid), in the valley of the Chacimayu south-

west of Cuzco.* In many valleys glacial features are developed at a much higher level. In other valleys outside the Cuzco basin the limits of glaciation are much lower. For example, between Ollantaytambo and Torontoy, well-developed terminal moraines at least 400 feet high stand but 8,500 feet (aneroid) above sea level.

Besides striæ the glaciated valleys exhibit slopes of character-

FIG. 11.

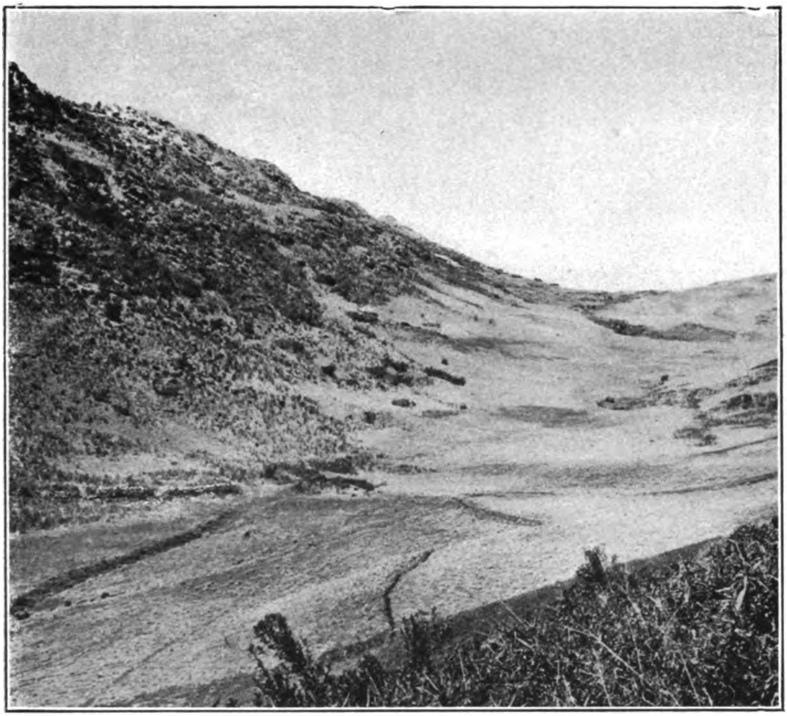


FIG. 11. Glaciated head of the Chacimayu valley. Note the smooth floor and steep sides. Looking up-valley from station in which fig. 12 was taken.

istic pattern. Fig. 11 represents the glaciated head of the Chacimayu; fig. 12 represents the unglaciated lower and

* Near the fortress of Sacsahuaman, north of Cuzco, is a famous grooved and striated knob of rock. The remarkable nature of the grooves has often been described though never properly interpreted. Proof that the surface was slickensided and not glaciated will be presented in a later paper on the geology and geography of the Cuzco basin.

tributary to the unglaciated part of the valley. In time the entire flat-floored portion will be dissected to the point where no flat floor remains; the steep marginal walls will ultimately be reduced in gradient, and the striæ obliterated. The form of the upper valley will then harmonize with the form of the unglaciated portion of the valley farther down. If the gravels had been deposited in post-glacial time, glacial forms in the valley heads would be destroyed by that great headwater erosion which the valley alluvium demands.

The bluff in whose face the Cuzco man and associated vertebrate remains were found leads up by steep slopes to a broad, smooth, and almost flat-topped gravel spur, one of a group of spurs whose upper surfaces fall into a common plane as in fig. 1. In all cases the borders of the spurs are marked by bluffs of steep descent, indeed in many cases they are unscalable and the infrequent paths run by selected routes. The highest bluffs rise several hundred feet above the valley floors. Their height and steepness are clearly dependent on the climate, which is semi-arid and marked by light, infrequent rains. Seepage lines are rare and occur only at low levels. So coarse and steep are the bluffs, so well drained, and so scantily watered that many of them exhibit not the slightest sign of seepage though all bear on their surfaces and margins signs of water action. Later alluvium derived from older rock waste is in evidence everywhere either as a fringe about the bases of the bluffs or as long trailing masses of gravel along the dry channels of the tributary streams.

The relation of the bones to the surface of the bluff leads to some important considerations. The finding of material on the immediate face of the bluff does not merely by virtue of that position indicate with certainty natural burial during the upbuilding of the formation and reëxposure as a result of present erosion. Though the bluff is very steep, a number of plant forms cling to it. These catch particles of falling or sliding material and even pieces of pottery. In a number of cases it was noted that the vegetation responsible for such obstruction in time dies and may be entirely or almost entirely removed. Surficial objects are then left attached to the face of the bluff, from which they may be easily removed. The steeper the bluff the more difficult the retention on a sloping surface becomes. The patchy mantle of foreign material is always loose, unstratified, fine-textured, and in strong contrast to the undisturbed material directly beneath it. As contrasted to such surface drift, it is noteworthy that the vertebrate remains were not on the face of the bluff but eight inches back from the face measuring to the median line of the deposits: also that they were stratified with the gravels,

mixed with material of about the same texture and composition, and that they lay in a nearly horizontal plane.

The form of the bluff at the locality in point may be appreciated by the photograph, fig. 4, and by the profile, fig. 10, based on measurements. The topographic relations and the

Fig. 13.

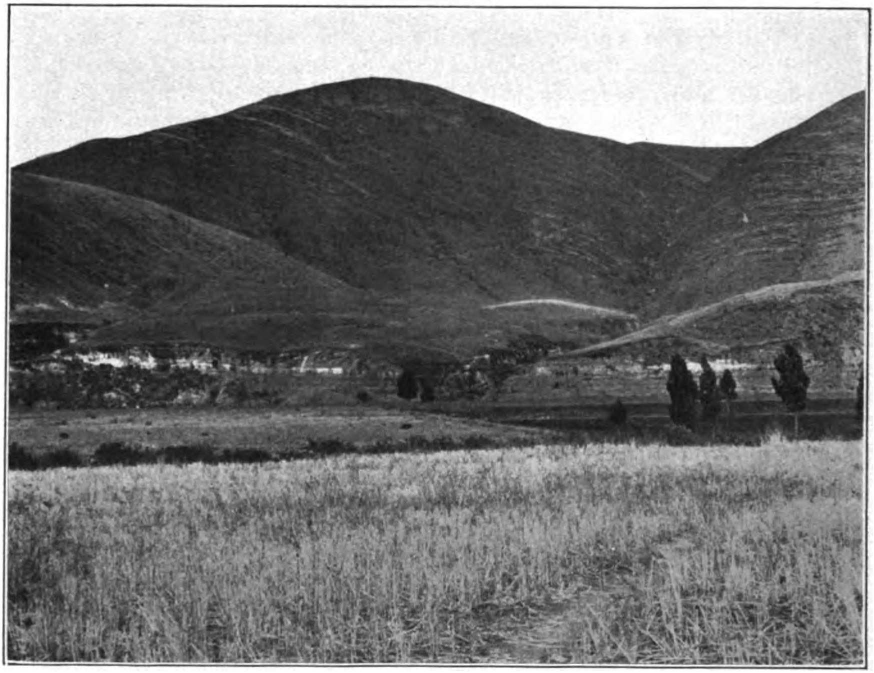


Fig. 13. Mountains on the border of the Cuzco basin. The white strata of the terrace at the foot of the mountain are of Tertiary age. The alluvium covered floor of the basin shows in the foreground.

geographic position may be understood from the maps (Plates I and II), which exhibit so many details that further description is hardly required.

Age of Deposits.

In order that the antiquity of these remains may be considered in a concrete way, we shall now examine the deposits with a view to determining their age. It may be clearly seen from fig. 10 that the coarse gravels of the region are the upper-

most of two glacial series. The coarse deposits and not the lower fine deposits have intimate relations with glacial material in the higher valleys. Therefore the coarse deposits were formed at the time of the *last* glaciation. Although two periods of glaciation may be identified throughout the Central Andes, I have nowhere been able to find any evidence of great differences of age. The lower, finer, eroded deposits appear to be in as fresh a condition as the overlying coarse material both at the contact and below it. This suggests that the deposits may correspond to those of the earlier and later Wisconsin glacial stages, the last in a series of six glacial epochs of which evidence is found in central North America.

The topographic and drainage relations that in the United States have made it possible to estimate the age of the deposits of the last glacial invasions, and indeed of some of the earlier ones, are not duplicated in the Central Andes; nor have I been able to find other relations that will serve the same purpose. Estimates of the age of glacial deposits in South America rest upon comparison with glacial deposits in the northern hemisphere and the conclusion that glaciation was contemporaneous in the two hemispheres; in other words, that the climatic conditions which produce glaciation are of cosmic origin. Although I have studied the glacial deposits of the Central Andes in a great variety of climates and have examined glacial deposits in six of our northern states and in Canada, I can see no essential difference in the degree of weathering. The striking feature in all cases is the freshness of the material and the comparatively youthful, in many cases merely incipient, erosion of glacial forms. Direct evidence of contemporaneity has been presented by Steinmann.* In a later paper the writer will present a new line of evidence in support of the same conclusion.

If we take contemporaneous glaciation in the northern and southern hemispheres as the basis for further consideration, we shall have as the age of the older deposit of the first epoch 40,000 to 150,000 years and the age of the later coarse deposits in which the Cuzco man was found as 20,000 to 60,000 years. The layers in which the bones were found do not lie higher than midway in the coarser series; I should be inclined, were it not for the remains in them, to place them in the lower half of the coarser series, which would give them 40,000 to 60,000 years.† A conservative statement then is that the bones appear to be from 20,000 to 40,000 years old, or that they have

* Über Diluvium in Süd-Amerika, von G. Steinmann, Sonder-Abdruck aus den Monatsberichte der deutschen-geologischen Gesellschaft, Jahrg. 1906, Nr. 8/10.

† See Chamberlin and Salisbury, Geology, vol. iii, 1906, p. 420.

been buried from three to six times longer than the historic period.

The Scandinavian geologists argue for a much shorter post-glacial period than American geologists have heretofore conceded.* Their time estimates, calculated on the basis of the thickness, rate of formation and character of clay and bog deposits, give the post-glacial period a length of 15,000 to 20,000 years or less. We have to note of course that their results, based on facts gathered much nearer the center of an old ice field, are not strictly comparable with results from Niagara and the Finger Lakes district, near the edge of the glaciated country. All of these figures should be regarded as rough estimates which express an opinion, or as a calculation with a wide margin of error.

Conditions of Burial.

One asks at once how the bones could be preserved for so long a period. We are all familiar with the decayed condition of bones buried for even a short period of 20, 50, or 100 years. The bones of the Cuzco man are distinctly weathered but they do not fall apart. They are so fragile that we broke some of them in excavation though we used great care; yet they are sufficiently firm, or at least some of them are, to display a clean mark when scratched with the knife. On the whole their comparative freshness is striking in view of a probable age of 20,000 to 40,000 years. On the other hand, it must be remembered that human bones equally well preserved have been recovered from the shell heaps and kitchen-middens of Europe; that human bones no more decayed than these have been found in far older glacial deposits in France, Switzerland, and England; and that more important than the question of state of decay is the question of conditions of burial. The position of the bones within the zone of weathering, the character of the material, the climatic conditions, and the state of the bones at the time of burial are all-important considerations which are discussed in the following paragraphs.

The bones of the Cuzco man, as well as the related vertebrate remains, all show a certain degree of erosion as if they had been for a short time in the grip of a stream. The finer details are wanting and projecting points are moderately worn. The facts that only the projecting points are rounded and the finer detail lost on the more exposed portions and that the amount of erosion is small argues distinctly in favor of the *freshness of the material at the time of burial.* If the bones had

* See especially the collection of papers published by the International Geological Congress, Stockholm, 1910, under the title: "Die Veränderungen des Klimas seit dem Maximum der letzten Eiszeit."

been decayed before being caught by the aggrading stream, their more fragile portions would be worn, though not without respect to exposure of more projecting parts. The projecting points are not necessarily the parts to decay more readily. It may be safely argued from these two conditions also that the bones were decidedly fresh at the time of burial, a condition favoring long preservation.

The bones lay in the zone of weathering, that is to say in the zone between the surface and the ground water. At the time the deposits were forming over them they undoubtedly lay for a part of the time in the ground water and not in the zone of weathering. When the deposits were later eroded and the present ravines formed, the level of the ground-water zone was lowered to the point where the bones once more lay in the zone of weathering. The *rate* of weathering is, however, not uniform in this zone; it is accelerated by strong temperature changes, by pronounced rise and fall of the ground water with the wet and the dry seasons, and by a greater amount of capillary water surrounding the soil grains. It is also hastened by soil acids which in turn depend upon conditions of drainage and of vegetable growth, being most abundant where the vegetation is abundant and the drainage poor.

Organic material buried in the gravel deposits of the Cuzco region at some depth in general would be well-preserved because of (1) the thorough drainage, (2) the absence of important amounts of vegetable acids in the soils owing to the rapid drainage and the scanty vegetation, (3) the absence of strong changes in temperature during the greater part of the period of burial, and (4) occurrence during the later stages of erosion on the face of a bluff where, though air could penetrate, the bones were surrounded by material almost air-dry.

The Nature of the Evidence.

Very few of the published arguments for the antiquity of human remains rest, as in the present instance, upon physiographic facts. It is, therefore, necessary to indicate the nature of the physiographic evidence herein presented, its strong and its weak points, and particularly, the necessity for its use. The gravels have no fossils that in themselves throw light upon the age of the beds; the long erosion interval between the inclined and dissected Tertiary strata and the glacial gravels overlying them still further reduces the value of purely stratigraphic evidence; and the gravels are in process of vigorous dissection to-day, hence they were formed at some past time. We have, then, to deal with a phase of recent geologic history, without being able to rely upon any facts of structure or

stratigraphy. It follows, that without a recognition of the physiographic evidence, no determinations of the geologic age of the deposits could be made. Indeed, archæology in general deals so constantly with surface deposits, their thickness, rate of formation, geologic relations and probable age, that archæologic collections can not be properly made if related physiographic facts are ignored.

The original plan of the Expedition did not include excavation or detailed archæologic work, nor was any effort made to do highly detailed geologic work. It was essentially an exploratory expedition. Furthermore, I came to the study of the bones, and the gravels in which they were embedded, with grave doubts as to the value of the find. A rather extended reading of anthropologic literature bearing on the antiquity of man convinced me, some years ago, that almost all of our reported cases of buried human remains in North America are not authentic, or the arguments are not sound. I expected to find some doubtful evidence that would entirely destroy any supposed value the Cuzco material might have. Upon examination the geologic evidence appeared very convincing and the proof clear. At the least a detailed study of the physiographic geology of the head of the Cuzco basin was demanded. When this study had been completed, I again returned to the bone locality, in a skeptical frame of mind, prepared to find some fact that would destroy my former arguments.

There is not the slightest thread on which I am able to hang any positive doubt, save the arch of material over the bones. It was at first thought to be either the natural arch of the top of a grave or a dividing plane between an earlier and a later deposit, and that the bones lay in the outer, later deposit, made long after the glacial period. The former hypothesis proved to be untenable, because the gravel became firm before the bones were reached, while excavating downward from the crack. In testing the latter hypothesis, a similar difficulty arose. No break could be found between the stratified gravel of fig. 5 and the stratified gravel in the steepest part of the bluff. Although a search was made for signs of a break, showing that erosion was followed by alluviation, and for facts showing that the fill material contained the bones, nothing conclusive or even suggestive could be found.

If, upon excavation, material should be found which clearly indicates the burial of remains belonging to species introduced by the Spaniards, it will have to be concluded that a break exists between the gravels on the face of the bluff and the gravels in the main mass of the spur. It will then be necessary, even if not before, to excavate until the position and character of the break are definitely determined. Should such

evidence be found (and only excavation appears to be capable of finding it), we shall have to conclude that the lowest terrace was still aggrading at the time of the Spanish Conquest and that after the aggradation cycle had been completed, degradation followed, the valley being worn down to a depth of about thirty feet.

The bovine cannon bone and rib of the Cuzco collection resemble bison more than they do modern domesticated cattle. But apart from the present find there is no evidence that the bison existed in South America, and while it is possible that its remains may yet be found, it is very suggestive that none have been reported until now. It is, of course, necessary always to find the first occurrence. Nevertheless, there is a basis for doubt in the fact that the species has escaped discovery until now. Further excavation is needed, for the same body of gravels may yield material that will put the conclusions upon a more solid foundation. If later studies should yield evidence in favor of the conclusion that the material belongs to the Spanish period, we shall have still the fact of interstratification as a starting point, and the conclusions based upon that fact will have almost equal interest with the conclusions here stated, as to the glacial age of the material. Changes of such magnitude indicate a swing of the climatic pendulum but little short of remarkable.

Art. XXVIII.—*Report on the Remains of Man and of Lower Animals from the Vicinity of Cuzco, Peru*; by George F. Eaton.

The vertebrate remains described in this report were discovered in the vicinity of Cuzco, Peru, by Professor Hiram Bingham, Director of the Yale Peruvian Expedition of 1911. To him I am indebted for the privilege of studying this interesting and valuable collection.

Under the List of Genera and Species are enumerated the specimens that are sufficiently characteristic for identification. Each bone is numbered in this List, so that by turning to the corresponding numbers in the following Description of Material, further information regarding the more important specimens may be found.

List of Genera and Species.

Homo sapiens.

(Representing at least three individuals.)

1. A fragment of the cranium.
2. An imperfect 5th thoracic rib.
3. An imperfect 9th thoracic rib.
4. Fragments of a right os innominatum.
5. A nearly complete right femur.
6. An imperfect left femur.
7. A fragment of a right femur.
8. Several fragments of the shaft of a left femur.

Canis sp.

9. The shaft of a left tibia.

Bos sp.

10. A left metatarsus.
11. A fragment of a right radius.
12. A fragment of a 1st right thoracic rib.

Lama guanacus.

13. A nearly complete left tibia.
14. The ends of a left tibia.
15. A fragment of a left humerus.
16. A left calcaneum.

Description of Material.

Homo sapiens.

The human remains comprise the following specimens:

1. An irregular fragment of a right parietal bone, measuring about 7·5^{cm} along the sagittal suture and 2·0^{cm} along the coronal suture. Posteriorly the fragment is about 6·0^{cm} wide. The sutures are moderately tortuous, and the bone, which is of fair but not remarkable thickness, is presumably from an adult skull. The outer and inner tables are firm and well preserved, the latter showing the Pacchionian depressions and the characteristic grooves made by the branches of the middle meningeal artery. It is, of course, useless to attempt to describe the particular type of cranium represented by such a small fragment further than to state that the sagittal and transverse curvatures are moderate rather than extreme, and present no

FIG. 14.

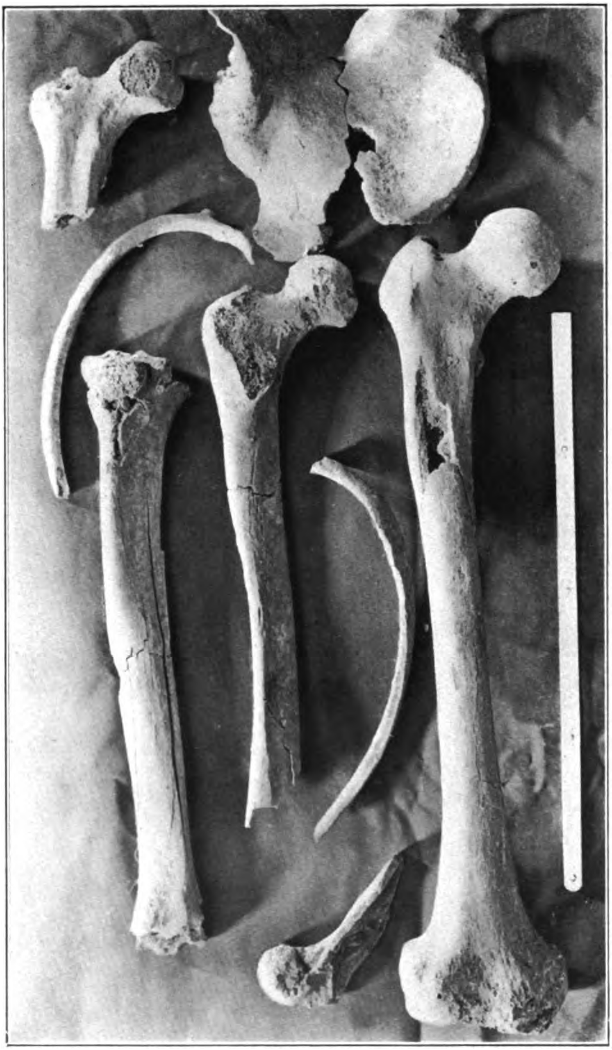


FIG. 14.* General view of the principal human bones.

indications whatever of pathological or artificial deformation. The fragment is too short to show the presence or absence of an interparietal bone, the so-called os Incæ.

2. An incomplete right 5th thoracic rib.

* For figures 1–13 inclusive see the two preceding articles.

FIG. 15.

FIG. 15. General view of the bone fragments and of some of the human bones of fig. 14.

3. The greater part of a right 9th thoracic rib of fairly robust character, though not of especially large size.

4. An incomplete right os innominatum in four fragments. Practically all that is preserved is the ilium, the pubis being

lost, as well as nearly the whole of the ischium, with the exception of a little of the ischiatic portion of the acetabulum. The imperfect condition of this bone and the absence of the sacrum render it impossible to measure all the pelvic diameters and to calculate the conventional pelvic indices; but an approximate idea of the size of the pelvis may be obtained from the following linear measurements :

From the posterior superior spine to the anterior superior spine, 16·0^{cm}.

From the summit of the iliac crest to the nearest point on the acetabular rim, 12·0^{cm}.

This bone is of massive form throughout, with well-developed rugosities. That it is from a male skeleton is further shown by the absence of a prae-auricular sulcus. Possibly this pelvis belonged to the same individual as the bone next described.

5. A nearly complete right femur. The contours of the ends of this bone are massive in proportion to its length, and the shaft also is well developed, though not especially large. It is necessary to record here only a few of the measurements that have been taken of this femur, in order to indicate its essential form.

Measurements of Femur, Bone 5.

(1)	Physiological length, or length in oblique position	42·4^{cm}
(2)	Trochanteric length	41·1
(3)	Transverse diameter at a point 3^{cm} distal to the most prominent part of the lesser trochanter	3·6
(4)	Antero-posterior diameter at same point	2·6
(5)	Index of superior platymeria $= \frac{(4)\times 100}{(3)}$ (This is a ratio, not a metric length.)	72·2
(6)	Transverse diameter at middle of shaft	2·7^{cm}
(7)	Antero-posterior diameter at middle of shaft	2·9
(8)	Proximal breadth, taken from the free surface of the head across the great trochanter	9·6
(9)	Vertical diameter of head	4·8
(10)	Transverse diameter of head	4·7
(11)	Collo-diaphysial angle, approximately	119°
(12)	Maximum transverse diameter of distal epiphysis	8·8^{cm}

The distal end of the femur is also characterized by a wide inter-condylar notch. No comparison can be made of the antero-posterior lengths of the condyles, as the median condyle is imperfect. The curvature of the shaft is slight. The linea aspera is prominent, as indicated by the pilastric index of

107·7, obtained from the diameters at the middle of the shaft. The gluteal line is well developed, but there is no actual third trochanter. The anterior inter-trochanteric line is indistinctly marked, and the anterior surface of the shaft immediately below this line is slightly concave, while the external surface of the upper part of the shaft is bowed a little outward. The resulting platymeria, or femoral flattening, does not, on the whole, afford any satisfactory racial indications. Manouvrier attributes platymeria to excessive use of certain muscles of the leg in climbing steep slopes—a theory that is not ill-suited to the present case, the topography and geology of the region where the bone was found also favoring the supposition that we have to do with a hill-man or mountaineer.

The form and size of this femur, as recorded in the foregoing measurements and description, fall within the range of femoral variation in normal adult male Peruvians of the later Inca period. I have already stated that this femur may possibly have belonged to the same individual as the pelvic fragments, bone 4. The two bones are of compatible size and form, and would represent a thickset and muscular man about 5 feet and 4 inches ($1·625^{m}$) in height (fig. 14).

It is clear that no proof of great antiquity can be drawn from the characters of the human skeletal parts submitted to me, agreeing, as they do, in all essential respects with the bones of a recent people. Until additional skeletal material is obtained, showing characters more primitive than those already noted, the burden of proof of great antiquity must rest on geological and paleontological evidence.

6. An imperfect left femur of considerably smaller size than that designated as number 5. While of the same general type as the larger bone, it is a little less robust in its proportions. The proximal end is poorly preserved and the distal end is missing. A very crude calculation gives a physiological length of $38·0^{cm}$ (15 inches).

7. The proximal portion of a right femur of nearly the same size and form as number 6.

8. Several fragments from the shaft of a left femur of about the same size as number 6.

Canis sp.

9. The shaft of a left tibia. Although this bone is much battered, and both ends have been broken off, it is clearly from the skeleton of a wolf or wolf-like dog. It closely resembles the tibia of a small Gray Wolf, *Canis occidentalis.*

In this connection it is interesting to note that three distinct varieties or breeds of domestic dogs are known to have existed in Peru during the later Inca period. Dr. Nehring has described

these as follows: (1) A small-sized breed of the bulldog or pugdog type, characterized by a short snout, with undershot jaw; (2) a small house-dog like a Dachshund, with slender snout; and (3) a larger slender-limbed dog, with wolf-like skull, originally described by Tschudi under the name *Canis ingæ pecuarius.* According to Dr. Nehring, the two smaller breeds were derived from the larger wolf-like variety, which, he states, was itself derived from the American wolf. The presence of a tibia of a large wolf-like dog among the bones collected at Cuzco, while it offers no proof of great antiquity, certainly does not in any way render such a view untenable.

Bos sp.

10. The metatarsus, or "cannon bone," of the left hind leg. The length of the bone without the distal epiphysis, which was not preserved, is $19{\cdot}0^{cm}$, or 7½ inches. Subsequent to the loss of the epiphysis, and prior to deposition in the locality where found, the bone has been eroded to such an extent that the sharp edges of its modelling are destroyed.

11. A small fragment of a right radius.

12. A fragment of a 1st right thoracic rib.

Realizing the importance of determining whether these bovine remains belong to a feral or to a domestic race, I have endeavored to obtain all possible evidence on this difficult question. As these fragmentary bones (10, 11, and 12) are among the least characteristic parts of the skeleton, their exact specific identification is beset with almost insuperable difficulties. While it is a simple matter to distinguish the hind cannon bone of a slender-limbed dairy cow from that of an adult Bison, a careful study of a large series of specimens shows that metatarsi of an intermediate type exist, which baffle specific identification unless accompanied by other more characteristic skeletal parts. This is true of the cannon bone designated as bone 10. The fact that the epiphysis is missing warrants the supposition that the bone is from a young animal, and accordingly had not attained its full growth. The fragment of a radius (bone 11) is too meager to be of any assistance in the present search for specific characters. The bovine specimen that is of greatest interest is the fragment of a 1st rib, designated as bone 12. I have examined the 1st ribs of the following Bison, *Bos americanus:* An adult male and an adult female in the Yale University Museum; an adult male and a young female in the U. S. National Museum; and an adult male and a young female in the Museum of the Brooklyn Institute of Arts and Sciences. In all these, the origin of the external intercostal muscle is marked anteriorly by a well-

defined ridge on the lower third of the bone, near its posterior border, and the external surface of the rib anterior to this ridge is somewhat flat and approximately parallel to the plane of the internal surface. As might be expected, the 1st ribs of the females and of the younger animals of both sexes have the ridge less strongly marked than is the case with the older males. The 1st rib of the extinct Bison, ***Bos occidentalis***, has essentially the same typical form. I have also examined the 1st ribs of a number of domestic cattle, the ***Bos taurus*** of zoologists, including two dairy cows, three well-grown beef animals of uncertain breed, and two fully adult Long-horned Texas Steers. In all these examples of ***Bos taurus***, the ridge that bounds the origin of the external intercostal muscle anteriorly is placed much further forward on the lower end of the bone, and no such extensive flattened surface appears in front of this ridge as was noted in the examples of ***Bos americanus***.

In respect to these apparently differential characters, the fragmentary bovine rib from Cuzco, designated as bone 12, is of the form that appears to be characteristic of the Bisons, and differs from the form seen in all the domestic cattle that I have examined. However, it resembles the rib of a female Bison or of an immature male, rather than the rugose rib of a mature male.

Since a fair statement includes a reference to all possible adverse evidence, it is well to note here that the 1st ribs of the Zebus, or Brahmin cattle, *Bos indicus*, are variable in form, and intermediate between the Bisontic and Taurine types. But the possibility of Zebu ancestry affecting the form of the 1st ribs of any South American cattle would seem extremely remote, because, as Professor Lydekker states in his work *Oxen, Sheep and Goats of All Lands, Living and Extinct:* "There being no other primitive wild ox [other than ***Bos taurus primigenius***, the Aurochs] in Europe, and an Eastern derivation in the highest degree improbable, it is evident that all the domesticated breeds of European cattle must trace their ancestry to the aurochs. It may indeed be admitted that some of the breeds—especially those of Eastern Europe—may have crossed with African or Indian cattle, but this does not affect the general proposition."

It cannot be denied that the material examined suggests the possibility that some species of Bison is here represented, yet it would hardly be in accordance with conservative methods to differentiate Bison from domestic cattle solely by characters obtained from a study of the 1st ribs of a small number of individuals.

If the material collected at Cuzco dates from a time preceding the Spanish Conquest, it would of course appear that the bovine bones included in the collection pertain to some species of Bison, for no other feral group of the Bovidæ need be considered. Such a conclusion, while by no means untenable on general grounds, might not be readily accepted by zoologists familiar with the principles concerned in the distribution of animals; for, although it is recorded that the Spaniards found *captive* Bison at Montezuma's capital, the American Bison in the free state is not known to have ranged further south than the northeastern provinces of Mexico.

13, 14, 15, and 16. These more or less fragmentary bones are confidently referred to *Lama guanacus*, the Guanaco, the feral species from which the domestic breeds of Llama and Alpaca are supposed to be derived.

No attempt has been made in this report to render any account of the chemical composition of the material described, as the conditions governing the destruction of osseous tissue, its mineral replacement, etc., are so varied and uncertain that chemical changes in the broader sense are no longer regarded by the highest authorities as reliable criteria of age.

Yale University Museum, March 15, 1912.

Art. XXIX.—*The Estimation of Lead, Nickel, and Zinc by Precipitation as Oxalates and Titration with Potassium Permanganate*; by H. L. Ward.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccxxix.]

Determination of Lead.

Reis in some investigations on the use of oxalates in analysis precipitated lead as the oxalate* by adding ammonium oxalate to a neutral solution of a lead salt and breaking up the resulting soluble double oxalate with a large excess of acetic acid. The insoluble lead oxalate was filtered off and ignited, and the lead was weighed as the oxide. It was thought that lead oxalate precipitated under these conditions might be of such composition that titration with permanganate would give a true estimate of the amount of lead present.

In the experiments of Table I the oxalate was precipitated by the addition of solid ammonium oxalate to the boiling solution of lead nitrate, containing the amount of acetic acid specified. The precipitate was collected on asbestos in a perforated crucible, and washed with small amounts of water. The oxalic acid was then set free by treatment with warm dilute sulphuric acid and titrated with potassium permanganate.

Table I.

The Determination of Lead by Precipitation with Ammonium Oxalate in the Presence of Strong Acetic Acid.

Lead present as the nitrate	Volume at precipitation	Acetic acid present	Ammonium oxalate	Lead found	Error
grm.	cm^3	cm^3	grm.	grm.	grm.
0·0050	100	25	3	0·0016	−0·0036
0·0250	100	25	3	0·0246	−0·0004
0·0500	100	5	3	0·0454	−0·0046
0·0500	100	10	3	0·0480	−0·0020
0·0500	100	25	3	0·0496	−0·0004
0·0500	200	50	7	0·0477	−0·0023
0·0050	100	50	4	0·0048	−0·0002
0·0050	100	50	4	0·0045	−0·0005
0·0250	100	50	4	0·0256	+0·0006
0·0250	100	50	4	0·0250	±0·0000
0·0500	100	50	4	0·0505	+0·0005
0·1000	200	100	8	0·1002	+0·0002

It will be noticed in the first part of the table, where the amount of acetic acid does not exceed one-fourth of the solu-

* Ber. Dtsch. Chem. Ges., xiii, 502.

tion, that precipitation is incomplete. If, however, glacial acetic acid makes up one-half the volume of the solution the results are accurate.

Oxalic acid has been used as a precipitant for lead by a number of investigators.* The determinations of Table II were made by adding crystallized oxalic acid to a boiling solution of lead nitrate, filtering, washing, and titrating the oxalate with permanganate as before. When no acetic acid is present, precipitation is not quite complete, but the errors are much less than when ammonium oxalate is used as a precipitant, as may be seen from a comparison with Table I. Acetic acid added in equal volume to the solution secures complete precipitation even in the presence of considerable amounts of ammonium or potassium salts, provided the amount of lead salt present is not too small.

TABLE II.

The Determination of Lead as Oxalate by Precipitation with Oxalic Acid in the Presence of strong Acetic Acid.

Lead present as nitrate	Volume at precipitation	Acetic acid	Oxalic acid	Salts present	Lead found	Error
grm.	cm^3	cm^3	grm.	grm.	grm.	grm.
0·0500	50	..	2	..	0·0491	−0·0009
0·0500	100	..	4	..	0·0488	−0·0012
0·1000	50	..	2	..	0·0994	−0·0006
0·1000	100	..	4	..	0·0990	−0·0010
0·0050	50	25	1	..	0·0050	+0·0000
0·0250	50	25	1	..	0·0256	+0·0006
0·1000	100	50	2	..	0·1002	+0·0002
			Potassium Acetate present			
0·1000	50	..	2	·2	0·0962	−0·0038
0·1000	100	..	4	·2	0·0988	−0·0012
0·1000	100	50	2	·2	0·0997	−0·0003
0·1000	100	50	2	·2	0·1000	±0·0000
			Ammonium Acetate present			
0·0050	50	25	1	3·	0·0040	−0·0010
0·0250	100	50	2	5·	0·0227	−0·0023
0·1000	100	50	2	2·	0·1000	±0·0000

† Böttiger & Pollatz, Chemical Abstracts, ii, 645: Mohr-Classen, Lehrbuch der Chemische Analytische Titermethode, 228; Low, Jour. Amer. Chem. Soc., xxx, 587.

Determination of Nickel.

Classen has shown* that nickel may be completely precipitated by treating the soluble nickel potassium oxalate with a large amount of acetic acid. The oxalate formed under these circumstances may be ignited to the oxide and weighed as such. It seemed desirable to determine whether this oxalate is of such composition as to allow the estimation of nickel by titrating the oxalate radical with potassium permanganate. The procedure first tried was that recommended by Classen. To a solution of a known amount of nickel sulphate was added a considerable excess of potassium oxalate and the liquid heated to boiling, when the oxalate first formed went into solution as nickel potassium oxalate. Two volumes of acetic acid were then added to precipitate the nickel oxalate. It was found necessary, in order to secure a product which could be filtered, to heat the acetic acid and to run slowly, with constant stirring, into the boiling solution of the double salt. Upon this treatment a flocky precipitate formed, which on standing for some time at 60°–70° went over to a fine powder. By filtration and titration with permanganate it was discovered that the oxalate obtained under these conditions had a tendency to include some of the precipitant, causing high results on titration. On ignition also large positive errors were obtained, but if the oxide was washed to remove the potassium carbonate formed, a very good estimation of the amount of nickel present was secured.

It seemed possible that the use of oxalic acid as a precipitant might eliminate the errors due to inclusion, but it was found that if oxalic acid was added to the boiling solution of a nickel salt containing an equal volume of acetic acid, the oxalate formed came down quickly and in an extremely finely divided condition. The first experiment of Table III was made in this manner, but in the majority of instances filtration proved to be impossible. If, however, precipitation was made in water solution and acetic acid added later to throw out the last traces of nickel, the oxalate came out more slowly and in a form suitable for filtration.

The nickel sulphate taken for analysis was dissolved in water and the solution standardized both by precipitation as nickelic hydroxide and ignition to the oxide and by throwing out as metallic nickel on the rotating cathode. To a definite amount of this solution, diluted to the required volume and heated to boiling, was added an excess of crystallized oxalic acid. Upon cooling, acetic acid was run in and the precipitate allowed to settle over night. The smaller amounts of nickel did not come out from the water solution, and even after adding acetic acid

* Classen, Zeitschr. anal. Chem., xvi, 470.

it was necessary to heat it to start precipitation. The nickel oxalate was filtered off on asbestos in a perforated crucible and washed with small amounts of water. The crucible was placed in a beaker containing about 25^{cm^3} of dilute (1:4) sulphuric acid and heat applied to effect the solution of the oxalate. The volume of the solution was then made up to about 200^{cm^3} and cobalt sulphate added until a slight pinkish tinge appeared. This procedure, recommended by Gibbs, was necessary to secure a definite end-point, as the green color of the nickel masked the complementary pink of the permanganate. The contents of the beaker were then heated to boiling and titration made in the usual manner. The results appear in

TABLE III.

The Determination of Nickel by Precipitation with Oxalic Acid and Treatment with Acetic Acid.

Nickel as sulphate	Volume of water solution at precipitation	Oxalic acid	Acetic acid added	Nickel found	Error
grm.	cm^3	grm.	cm^3	grm.	grm.
0·0503	100	2	50	0·0502	−0·0001
0·0050	100	2	100	0·0054	+0·0004
0·0251	100	2	100	0·0258	+0·0007
0·0503	50	2	100	0·0514	+0·0011
0·0503	100	2	100	0·0502	−0·0001
0·1257	100	2	100	0·1271	+0·0014

Table III. The positive errors may be assigned to two causes, inclusion of the precipitant and uncertainty of end-point when titrating in colored solutions.

Determination of Zinc as the Oxalate.

It was found to be possible to estimate zinc volumetrically as the oxalate by the process already outlined for nickel. In this case, no colored salts being present in the solution on nitration, a more definite end point was secured and the results obtained are much more accurate, as appears in Table IV.

TABLE IV.

The Determination of Zinc by Precipitation with Oxalic Acid and Treatment with Acetic Acid.

Zinc as acetate	Volume at precipitation	Oxalic acid	Acetic acid	Zinc found	Error
grm.	cm^3	grm.	cm^3	grm.	grm.
0·0055	100	2	100	0·0056	+0·0001
0·0274	100	2	100	0·0276	+0·0002
0·0548	50	2	50	0·0553	+0·0005
0·0548	100	2	100	0·0550	+0·0002
0·1370	100	2	100	0·1372	+0·0002

The oxalate of zinc obtained by the method of Classen* was contaminated with potassium oxalate and therefore could not be used to determine the amount of zinc present. On ignition and washing of the oxide obtained, it was shown that all the zinc was recovered.

Summary.

Experiments have been given to show that lead may be determined by precipitation, either with ammonium oxalate or oxalic acid, in the presence of large volumes of acetic acid and titration of the oxalate formed with permanganate.

Nickel has been estimated by precipitation by oxalic acid in water solution, the addition of acetic acid to separate the metal remaining in solution, and titration with permanganate. Errors may occur in this method from inclusion of the precipitant or indefiniteness of the end point.

Zinc may be estimated very accurately by the method used for nickel.

* Classen, Zeitschr. anal. Chem., xvi, 470.

Art. XXX.—*A Description of the Skulls of Diadectes lentus and Animasaurus carinatus;* by E. C. Case and S. W. Williston.

The two skulls here described have recently come to light. The first was collected by Case in the Baldwin Bone Bed on Poleo Creek in Rio Arriba County, New Mexico, and the second was collected by Baldwin near Animas, Colorado nearly thirty years ago, but has lain undescribed among the abundant material of Yale University. The matrix of the second skull, an indurated blue clay, is different from any occurring in the New Mexican localities, but the similarity of the skull to that of *Diadectes* and the geographical proximity indicate that it is a member of the same fauna.

Diadectes lentus Marsh. (Figs. 1 and 2.)

Nothodon lentus Marsh, this Journal, vol. xv, p. 410, 1878.
Nothodon lentus Case, Publication 145, Carnegie Institution, p. 30, 1911.
Nothodon lentus Williston, American Permian Vertebrates, Chicago, p. 16, 1911.

The only portions of the skull of this animal known previously were the few teeth described by Marsh and the imperfect top of a skull described by Williston in the paper cited above. The history of the discovery and description of the original specimen has been given by Williston in the paper cited above (pages 7 and 8) and need not be repeated. The uncertainty as to the generic identity of *Nothodon* and *Diadectes* has been removed by the discovery of this specimen associated with typical diadectid vertebræ with hyposphene and hypantrum in the original Baldwin bone bed.

The skull was found in a matrix of soft, blackish, friable clay on the banks of Poleo Creek about a mile above its junction with the Puerco river in Rio Arriba County, New Mexico. Closely associated with the skull were found the two jaws described in this paper and they would have been regarded as belonging to the same specimen if several other jaws of the same size had not been found with them.

The anterior portion of the skull, as far back as the postorbital region, was taken out in plaster and the relation of the parts can not be questioned. The posterior portion was broken in the ground and recovered as fragments. As restored, the skull resembles very closely that of *Diadectes* in form and proportions.

The top of the skull is very rugose in the occipital and frontal regions, but on the sides of the temporal and facial regions the bones are marked by a sculpture of fine pits. The

sutures can not be made out nor can any grooves such as figured by Williston (Am. Permian Verts., fig. 1 and pl. xxxviii) be seen. In the specimen figured by Williston the bones were separated and the sutures thus determined resemble very closely those shown in the single specimen of *Diadectes* from Texas, in which the sutures can be made out. Cope mentions the occurrence of grooves on the skull of *Chilonyx*, considering them to be the marks of attachment of corneous plates, but these could not be seen by Case. Seeley mentioned the occurrence of mucous grooves on the skull of *Pareiasaurus*, but this has been questioned. So far as we are aware, these are the only mentioned cases of anything resembling the grooves described by Williston. The only notable differences from the skull of *Diadectes phaseolinus*, the best known, are:

1. There are no pits on the surface of the supraoccipital bone.
2. The pits on the surface of the temporal region are very obscure and cannot be certainly distinguished from the deep interspaces of the rugosities.
3. There are small pits on the surface of the prosquamosal bones just anterior to the upper anterior border of the quadrate.
4. The jugal descends to the lower edge of the quadrate.

These differences are certainly not of generic value.

The *nares* are far anterior and in the crushed condition of the specimen appear to look upward; this is, however, an exaggeration of the natural condition, in which the nares were inclined somewhat inward and forward and looked almost directly outward. The nasal canal is inclined inward and downward and opens on the sides of the palatines and prevomers (vomers) at the posterior edge of the premaxillaries, a little posterior to the anterior opening.

The *orbits* are elongate oval in outline and inclined slightly inward at the upper edge.

The *parietal foramen* is, as in all the *Diadectidae*, 'enormous'. These are the only openings in the skull except the otic.

The *premaxillaries* are short and very heavy. Each one carries four strong incisor teeth (not two as described by Marsh) very prominent and protuberant; this is most evident in the median ones; the inclination becomes less in the outer teeth. The inner surface of the crown is beveled by a flat surface forming a strong chisel-like cutting edge. The surface of the crown is smooth but the roots are marked by deep striations. An isolated incisor tooth from another specimen has an imperfect root 22^{mm} long with the crown 17·5^{mm} long. There can remain no question of the true thecodonty of the teeth.

The *maxillaries* have the alveolar portion greatly swollen

to accommodate the wide sockets for the teeth. The outer portion, forming the sides of the facial region, is thin and marked with a sculpture of fine pits. The swollen portion departs abruptly from the inner side, forming a gently swelling prominence; from a point near the middle of the inner side of this swollen portion rises the palatine process of the maxillary which projects from the bone at a fairly steep angle and leaves a deep groove between it and the bone proper. The process is thin and the lower edge is slightly rugose. It extends in a gentle curve, following the outline of the inner edge of the maxillary, from the third or fourth tooth to beyond the last tooth. The character of this process has been in doubt, Cope and Case believing that it might possibly be the palatine bone, but the condition of this specimen leaves no doubt of its true nature. There are 11 maxillary teeth; the first has the form of the incisors except that the face is not so broad and chisel-like. It is smaller than the incisors and there is no approach to a canine character. The second is smaller than the first and more conical in form. Both of these are nearly vertical. The succeeding teeth, except the last, have the characteristic transverse widening; the first of these, the third of the series, has a sharp median cusp and the inner and outer edges are rounded; the rest, except the eleventh, have a median cusp and lateral cusps on the inner and outer edges, identical with the teeth of *Diadectes phaseolinus* Cope. The teeth increase in width to the sixth or seventh and then decrease to the posterior end. The eleventh is not preserved, but the outline of the base shows it to have been small and conical. When first erupted the enamel of the teeth was marked by rugose lines which radiate from the central cusp, but these are soon removed by wear, and in old individuals the surface is nearly flat. There is a deep pit on the inner side of the base of each of the teeth, marking the position of successional teeth.

The *prevomers* (vomers) are paired and articulate strongly with the premaxillaries in front, the pterygoids behind, and the palatines laterally. They are of considerable vertical extent and closely applied to each other in the median line. Case (Publication 145, Carnegie Institution, p. 71) has described the posterior ends of the prevomers as spreading apart above at the posterior end and receiving the lower edge of the ethmoid. It is now apparent that this open portion is the anterior end of the pterygoids or the posterior of the palatines. The lower surface of the prevomers is flat and there is a series of small, sharp, conical teeth about a millimeter in length. The posterior limit can not be determined as the suture between the prevomer and the pterygoid is not distinguishable.

The *palatines* are gently convex upward; the outer edge is

attached to the maxillaries throughout their length; there is no palatine vacuity. The position of the palatine-pterygoid suture can not be made out. The anterior portion of the inner edge of the palatine is applied to the outer surface of the prevomers, the attachment being by overlap. There are no teeth on the palatine.

FIG. 1.

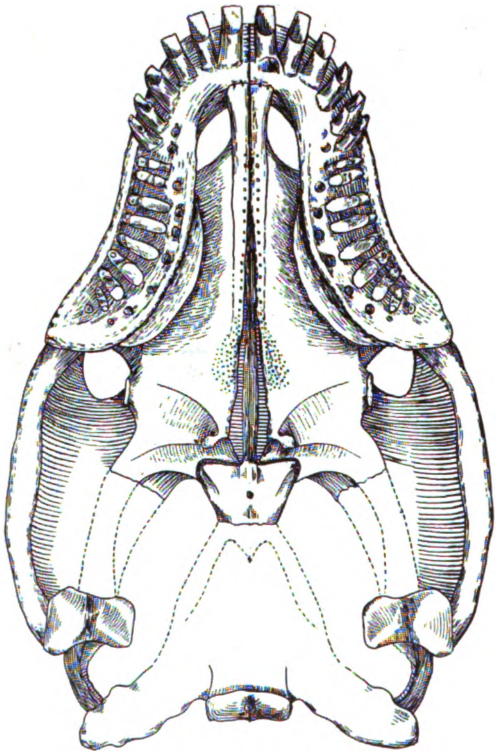


FIG. 1. Palate of *Diadectes lentus* Marsh. × ½. Mus. University of Chicago.

The *pterygoids* are slightly convex upwards in the anterior portion; the inner edges of the two bones meet, if at all, at the anterior ends, leaving an elongate vacuity which widens posteriorly. It is uncertain whether the anterior ends of the pterygoids meet or whether the vacuity is closed by the union of the prevomers (vomers). The edges of the pterygoids forming the sides of the median vacuity are lined with small teeth and the flat surface of the bone adjacent to the posterior part of the vacuity is covered with small shagreen-like teeth. The

middle portion of the pterygoid widens and is slightly concave on the lower face; this portion is marked by a low line convex anteriorly. On the outer side of the middle of the bone is the low ectopterygoid process: its outer edge and a portion of the upper surface is slightly rugose, but there is no approach to the prominence which the same process gains in *Labidosaurus* and *Captorhinus* and there are no teeth on the process. Near the median vacuity there is slightly prominence on the inner edge of the bone which curves inward and backward over the vacuity. The articulation with the basisphenoid is by strong flat faces. The pterygoids are separate from the basisphenoids in the specimen, but were found articulated in position so that the nature of the free articulation is beyond doubt. Posteriorly the pterygoids send the usual vertical plates back to join the quadrate.

There is no evidence of an *ectopterygoid*. This bone has been in question, but it seems to us there can no longer be doubt of its absence.

The *basisphenoid* is represented by the anterior end, only. There is a small but well developed foramen in the middle line. The parasphenoid rostrum is strong; the lower edge is thick and flat but the upper edge is thin and the whole bone becomes thin anteriorly; it terminates freely a little beyond the point where the median vacuity is closed by the approximation of the pterygoids or prevomers. It is apparently this bone which was figured by Case as the ethmoid in *Diadectes phaseolinus*. It is worthy of note that this bone, so strong in this specimen, is wanting in many of the described skulls of *Diadectes*, perhaps by accident, and it was originally reported that it was absent.

Above the parasphenoid process there are the shattered remains of very thin plates of bone which can not be restored. It is apparent that they were paired and that they reached up to the lower surface of the parietal or frontal bones. They are probably the anterior ends of the sphenoid plates described by Case.

The *quadrate* resembles the same bone in the specimen of *Diadectes* described by Case from Texas (No. 4839 Am. Mus. Nat. Hist.), but the shaft is a little longer and there is a prominent tuberosity on the posterior surface just above the articular surface. It is probable that there was such a tuberosity on the Texas specimen but that it was destroyed by the accidents of fossilization.

It is necessary here to correct certain errors in the restoration of the skull of *Diadectes* published by Broom (Bull. Am. Mus. Nat. Hist., vol. xxviii, Art. XX, pp. 216–217, figs. 11 and 12). In figure 11, the side view, Broom shows an enlarged anterior maxillary tooth resembling a canine, a diastema,

and a decrease in the size of the incisors from within outward. The character of the incisors is evidently hypothetical as they are shaded, but the arrangement is wrong as can be made out from this specimen and from several others in the American Museum. There is no diastema and in no specimen of *Diadectes* is there any indication of an enlarged maxillary. It was upon such an error that Cope founded the genus *Empedias*.

In figure 12, the palate, the arrangement of the bones is wrong. The premaxillaries are never so wide, antero-posteriorly, as figured; the prevomers extend much farther forward than figured; the palatine process of the maxillary is figured as a palatine; the pterygoids are figured as short bones with

FIG. 2.

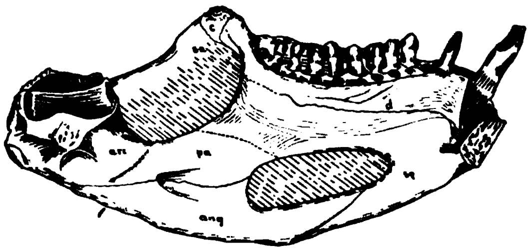


FIG. 2. Lower jaw of *Diadectes lentus* Marsh. × ½. Mus. University of Chicago.

the prevomers extending back as far as the posterior end of the maxillaries; an ectopterygoid is figured,—as already stated we find no evidence of such a bone in the *Diadectidæ*. We have studied the known skulls of *Diadectes* carefully for several years and have found no evidence to warrant drawing the sutures of the temporal region so definitely as Broom has done, though they may be correct.

The lower jaw.—The resemblance to the lower jaw of the specimens of *Diadectes* from Texas is very close, but the jaws from New Mexico show the sutures and permit the outline of the individual bones to be determined. On the inner side the suture between the splenial and dentary is distinct in front but is not traceable behind: its probable continuation is indicated by the dots in the figure. Below the anterior Meckelian opening the suture between the splenial and the surangular is very distinct. The splenial takes the usual large part in the symphysis. The suture between the angular and the bone above it in the posterior portion of the jaw is distinct, but it is somewhat uncertain what this bone is. The articular is not marked off by distinct sutures, but on the surface of the bridge between the anterior and posterior openings of the lower

jaw there is a low, slightly rugose ridge which appears to mark the portion of a suture which has closed. If this is true, the portion of the bridge behind the rugose line may be the anterior portion of the articular, and the anterior portion of the bridge may represent the prearticular; the ridge may, however, be only a surface for the attachment of muscles. The coronoid is a very small bone visible on the inner side of the jaw. The surangular behind and the dentary in front send processes upward which aid in the formation of the coronoid process. The sutures on the outer side of the jaw can not be made out except where a break in one of the jaws shows that the suture between the dentary and the surangular runs downward a little anterior to the coronoid process. The articular face of the articular has two deep parallel grooves which limited the motion of the jaw to the vertical plane. There are fifteen teeth in the jaw. The posterior one is small and conical; the next eight have the expanded form characteristic of the genus. The first four have the chisel-like form of true incisors, the fifth is nearly conical, the sixth has the crown slightly expanded and carries a single median tubercle. The other have wide crowns with three tubercles. The wear was on the outer side of the teeth in the lower jaw and the inner side in the upper.

Animasaurus carinatus, gen. et sp. nov. (Fig. 3.)

The specimen consists of a fairly perfect skull (No. 1107 Mus. Yale Univ.). It is slightly injured in the anterior part so that the premaxillaries, the anterior ends of the maxillaries and the nares are lost. The anterior portion of the facial region is crushed down upon the palate. The teeth are all destroyed, but the outlines of the roots show them to have been transversely expanded as in *Diadectes*. The condition of the specimen is such that the sutures can not be made out and the hard matrix can not be entirely removed from the palate, but enough has been taken away, aided by a fortunate break, to make the structure evident.

The superior surface of the skull.—Due to the position of the quadrate, the posterior portion of the skull is proportionately much broader than in *Diadectes* though the occipital portion is narrower. The surface is roughened by sculpture and the development of tubercular prominences which recall those of the genus *Chilonyx*. This appearance is heightened by the position of the quadrate, which slants inwards instead of lying nearly parallel to the lateral surface, narrowing the occipital region. The parietal foramen is very large, approximately 20^{mm} broad by 25^{mm} long. This opening is farther forward than in *Diadectes*, a line drawn through the posterior edges of the orbits cutting through it at near the center; in *Diadectes*

such a line passes anterior to the opening. The outlines of the various bones can not be made out but it is evident that the frontal was very short and took no part in the superior border of the orbit.

The lateral aspect of the skull.—Allowing for the crushed condition of the anterior end, the lateral profile resembles that of *Diadectes*. The orbits appear to be narrowed vertically, but this is evidently due to crushing. On the right side there is

FIG. 3.

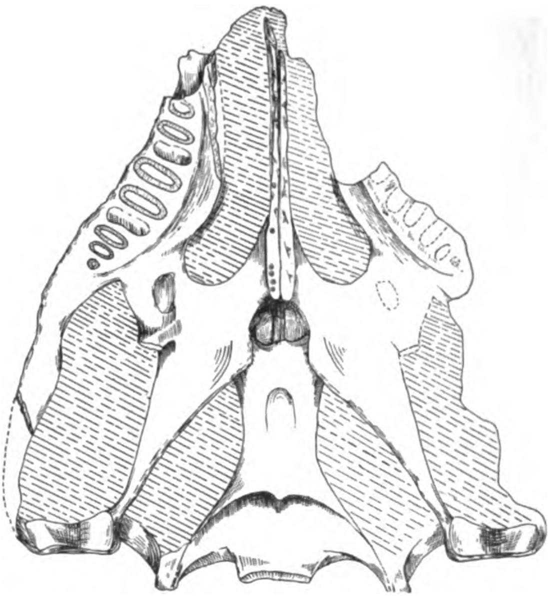


FIG. 3. Palate of *Animasaurus carinatus* Case and Williston. × ½. No. 817, Mus. Yale University.

a large opening in the temporal region but this is of accidental origin instead of a true temporal foramen, as is evidenced by the sharp break of the edges and the lack of a corresponding opening on the opposite side.

The palatal aspect of the skull.—This shows the great difference between this genus and *Diadectes*. The alveolar edges of the maxillaries are broadened as in *Diadectes* for the accommodation of the widened teeth, but the palatine process of the maxillary is perhaps different: it appears to rise from the inner edge of the alveolar surface instead of from the middle of the inner side of the swollen portion of the bone and there is no deep groove between it and the maxillary proper. The pterygoids and prevomers are united in the median line throughout their

length, forming a deep median keel; there is no median vacuity between the pterygoids but posterior to them there is a deep vacuity, the circular opening of which looks backwards and downwards at an angle of nearly 45° to the horizontal axis of the skull.

The posterior aspect of the skull.—The occipital portion is narrower than *Diadectes* owing to the position of the quadrates and the paroccipitals and exoccipitals are shorter. The articular face of the quadrate is much narrower than in *Diadectes* and the whole bone occupies a very different position with relation to the basicranium. In *Diadectes lentus* the quadrate lies much farther forward, the articular surface being opposite the posterior end of the basisphenoid; in *Diadectes phaseolinus* the articular face of the quadrate lies opposite the middle of the same bone, while in *Animasaurus carinatus* it lies posterior to the posterior end of the bone. This accounts largely for the wider appearance of the posterior end of the skull in the latter.

The individual bones can not all be made out, but such as can are described below.

The *maxillaries* are similar to those of *Diadectes* except as noted in the description of the palatine process. The posterior end of the bone is continuous with and on the same level as the jugal; in *Diadectes* it stands out as prominent point. There are nine bases of teeth and alveoli in the portion of the bone preserved. The posterior one was small and conical, as indicated by the base. The others are gradually enlarged until the 6 or 7 from the posterior end is reached, then they begin to diminish in size. There should be two more teeth in the maxillary if the number was the same as in *Diadectes.*

The *pterygoids* have the general form of those in *Diadectes;* the posterior vertical plate, reaching to the quadrate, is identical in form; the ectopterygoid process is similar but is more prominent. Laterally the pterygoid joins the maxillary with no indication of an ectopterygoid bone, but the sutures can not be made out. Anterior to the ectopterygoid process the bone widens and dips beneath the matrix, but it is apparent from a break on the left side that it joins the palatine and maxillary as in *Diadectes.* Just anterior to the ectopterygoid process there is a large shallow pit on the flat surface of the bone but there is no perforation. In fact there is not, in any American Permian reptile known to us, any indication of a lateral palatal opening or of a separate ectopterygoid. On the inner side of the bone the posterior portion rises abruptly to form the side of the circular vacuity anterior to the basisphenoid. Immediately in front of this opening the keel formed by the conjoined edges of the pterygoids of the two sides is very high.

The edges of the two bones forming the keel were lined with small conical teeth, now indicated by the bases. At the posterior end there are four such teeth in 15^{mm}; similar teeth can be detected throughout the length of the keel. No small teeth can be detected on the sides of the pterygoids adjoining the keel, but this may be due to the condition of the bone or the accidents of preparation; the surface of the bone is partly destroyed.

The *prevomers* are hidden by the matrix except the lower edge; it seems probable, however, from the appearance of the upper surface of the palate, revealed by the crushing of the facial region, that the palatines had the same relation to the prevomers as in *Diadectes.*

The *basisphenoid* is similar to that of *Diadectes* but is very much longer and there is no foramen in the median line. In the deep pit anterior to the basisphenoid can be seen the posterior end of a strong parasphenoid rostrum. The posterior end of the basisphenoid is not entirely cleared but it is quite similar in general form to that of *Diadectes.*

The *quadrate* is inclined inward so that its outer surface looks rather backward than outward. There is no indication of the pit opposite the anterior edge of the quadrate. The inner edge describes the same sharp curve as in *Diadectes* and there is the same deep notch at the upper end of the otic opening. The articular face is very much narrower than in *Diadectes*, the anterior posterior diameter being only $9{\cdot}5^{mm}$ and the transverse at least $24^{mm.}$ In *Diadectes lentus* the same diameters are 17^{mm} and 24^{mm}. Moreover the outer half of the articular surface is nearly the same width as the inner; in *Diadectes* the outer is much wider than the inner.

The genus evidently belongs in the family *Diadectidæ*, but may be distinguished by the following characters:

1. The union of the pterygoids in the midline to form, with the prevomers, a prominent keel.
2. The absence of any interpterygoid space.
3. The elongation of the basisphenoid and the absence of a foramen in the median line.
4. The inward inclination of the quadrates narrowing the occipital region.

The animal must have been similar in form and habits to *Diadectes.* It has been customary to regard the members of this family as herbivorous, but the strong, chisel-like incisor teeth, the absence of any power of trituration in the unworn maxillary teeth and the possibility of the use of the palatine processes of the maxillaries as accessory agents of mastication lead to the suspicion that the animals were not exclusively if at all herbivorous, and that they may have included the less well-protected invertebrates in their diet.

Art. XXXI.—*A New Volumetric Method for the Determination of Mercury*; by George S. Jamieson.

Among the methods that have been proposed for the volumetric determination of mercury, the titration in nitric acid solution by means of ammonium thiocyanate,* according to Volhard's method for silver, while it appears to be very accurate, is not generally applicable because it cannot be used in the presence of chlorides. The method of Rupp† consists in adding potassium iodide and an excess of sodium hydroxide to any mercuric solution, then precipitating the finely divided metal by means of formaldehyde, and, after acidifying with acetic acid, dissolving the metal with standard iodine solution and titrating back with sodium thiosulphate. This method is simple and rapid, and while it seems to be a good one for small quantities of mercury, my experience with it is that it gives seriously low results with amounts of mercuric chloride as large as 0·1 to 0·2 grams. Hempel's method,‡ which consists in titrating mercurous chloride (or iodide) with iodine and thiosulphate, is undoubtedly very accurate, if it is used with proper precautions to completely dissolve the mercurous chloride in the iodine solution.§

The method to be described is based upon the titration of mercurous chloride with potassium iodate in the presence of 15 to 20 per cent of actual hydrochloric acid and a small volume of an immiscible solvent, such as chloroform. This general method of titration is the well known one of L. W. Andrews,‖ but as far as is known it has not been applied previously to the titration of mercurous chloride. It has the advantage over Hempel's method in requiring only a single, very stable volumetric solution, instead of two solutions which cannot be preserved for a long time unchanged, while the method of titration appears to be no less exact. It is to be observed that the iodate titration cannot be applied to mercurous iodide without the employment of an entirely different factor, since the iodine would affect the results.

It has been found that mercurous chloride reacts with potassium iodate according to the theoretical requirements of the equation

$$4HgCl + KIO_3 + 6HCl = 4HgCl_2 + KCl + ICl + 3H_2O$$

* Cohn, Berichte, xxxiv, 3502: Rupp, ibid., xxxv, 2015.
† Ibid., xxxix, 3702.
‡ Sutton, 10th edition, p. 263.
§ Smith, Chem. News, cv, 14.
‖ Jour. Amer. Chem. Soc., xxv, 756, 1903.

In order to test the method, a solution of potassium iodate was standardized with pure sublimed iodine, using Andrews' titration under the same conditions as are described beyond for the mercurous chloride titration.

	Iodine taken	KIO_3 used	Wt. of I for 1^{cc}
A	·1003^g	11·8^{cc}	·00848^g
B	·1998	23·6	·00846
Average .	....	....	·00847

Since the reaction in the case of iodine is represented by the equation

$$4I + KIO_3 + 6HCl = KCl + 5ICl + 3H_2O$$

the strength of the potassium iodate solution was $1^{cc} = ·01572^g$ of HgCl.

For the following titrations a sample of pure mercurous chloride which had been dried at 130°–135° C. for several hours and well pulverized was used. The titrations were carried out in a glass stoppered bottle of 250^{cc} capacity in the presence of 20^{cc} of water, 30^{cc} of concentrated hydrochloric acid, and 6^{cc} of chloroform, with thorough shaking of the closed bottle between the additions of the potassium iodate solution. As is usual in such titrations, the chloroform globule at first increases in iodine color and then this color is gradually removed. The end-point is the disappearance of this violet color. It was observed that dried mercurous chloride reacts more slowly in this operation than the precipitated substance which was titrated without drying in some of the experiments to be described beyond, so that in this case very thorough shaking and occasional crushing of the lumps with a glass rod were required. The following table gives the results of the titrations:

	HgCl taken	KIO_3 cc.	HgCl found	Error
I	·4999^g	31·80	·4999^g	·0000^g
II	·5000	31·80	·4999	·0001
III	·5005	31·80	·4999	—·0006
IV	·6001	38·15	·5997	—·0004
V	·4999	31·80	·4999	·0000

The results show a very satisfactory agreement among themselves and with theory.

Since most kinds of organic matter do not interfere with this method of titration, it is applicable to various mixtures containing calomel. It was tried with calomel tablets containing milk sugar, after pulverizing several tablets to obtain a uniform mixture. Quantitative determinations of the calomel were also made by treating portions of the substance with water slightly acidified with hydrochloric acid and weighing

the washed and dried residue. The following results were obtained:

Substance taken	KIO_3 used	HgCl found
·4811^g	16·50^{cc}	53·91%
·6783	23·25	53·89
·1976	gravimetric	53·94
·5694	"	54·00

The method was applied also to the determination of mercury in a mercuric compound by converting the latter into mercurous chloride and then titrating. For this purpose weighed portions of mercuric chloride were dissolved in warm water with the addition of a few drops of hydrochloric acid; an excess of phosphorous acid solution was then added, and after thorough stirring the precipitate in each case was allowed to settle for about twelve hours. It was then collected on a filter paper and well washed with cold water. The precipitate with the paper was put into the titration bottle, and any precipitate adhering to the beaker and stirring rod was collected by wiping with a piece of filter paper and also put into the bottle. The titrations were carried out as previously described with the following results: (1^{cc} KIO_3 = ·013354^{g}Hg)

No.	$HgCl_2$ taken	KIO_3 sol. used	Hg found	Hg calc.	Error
I	·3934^g	21·7^{cc}	·2898^g	·2904^g	—·0006^g
II	·3107	17·2	·2297	·2294	+·0003
III	·4903	27·1	·3619	·3619	·0000
IV	·3315	18·3	·2444	·2447	—·0003
V	·3407	18·8	·2511	·2515	—·0004

The results show that the method is an accurate one.

Sheffield Scientific School,
New Haven, Conn., February, 1912.

Art. XXXII.—*A Volumetric Method for the Determination of Hydrazine*; by George S. Jamieson.

A method for the determination of hydrazine has been described by Rimini* and recently tested further by Hale and Redfield.† This is based upon the oxidation of the hydrazine compound in aqueous solution by the addition of an excess of standard potassium iodate solution, according to the following equation:

$$5(N_2H_4.H_2SO_4)+4KIO_3 = 5N_2+12H_2O+2I_2+2K_2SO_4+3H_2SO_4$$

The liquid is then boiled until the iodine is expelled and the excess of potassium iodate is found after cooling by adding potassium iodide, acidifying with sulphuric acid, and titrating with sodium thiosulphate solution. The chief objection to this method, according to Hale and Redfield, is the length of time required for the analysis.

The method to be described here is based upon the titration of hydrazine by potassium iodate in a strong hydrochloric acid solution, according to the general method of L. W. Andrews.‡ It has the advantages of being rapid, and requiring the use of only a single, very stable volumetric solution. Besides, as will be seen from the results that follow, it is very accurate.

In order to test the method, a solution containing 3·567 g. of KIO_3 in 1000^{cc} was prepared. According to the equation of the expected reaction

$$N_2H_4.H_2SO_4+KIO_3+2HCl = N_2+ICl+3H_2O+KCl+H_2SO_4$$

the equivalent of this solution is 1^{cc} = ·002169 g. $N_2H_4.H_2SO_4$ and 1^{cc} = ·000534 g. N_2H_4. Weighed portions of pure hydrazine sulphate were placed in a 250^{cc} glass stoppered bottle together with 20^{cc} of water, 30^{cc} of hydrochloric acid and 6^{cc} of chloroform. Then the potassium iodate solution was run in gradually, with shaking between the additions, until the chloroform, after increasing and then diminishing in color, was just decolorized. The following results were obtained:

	$N_2H_4.H_2SO_4$ taken	KIO_3 used	$N_2H_4.H_2SO_4$ found	Error
I	·0487g	$22·5^{cc}$	·0488g	+ ·0001
II	·0434	19·9	·0432	— ·0002
III	·0589	27·3	·0592	+ ·0003
IV	·0472	21·9	·0475	+ ·0003
V	·0986	45·65	·0990	+ ·0004
VI	·1060	49·00	·1063	+ ·0003

* Gazz. chim. ital., xxix, I, 265, 1899.
† Journ. Amer. Chem. Soc., xxxiii, 1362, 1911.
‡ Journ. Amer. Chem. Soc., xxv, 756, 1903.

Determinations of hydrazine in the sparingly soluble double sulphates of zinc, cobalt, nickel, and cadmium were made in order to test the method further. The double salts were prepared by mixing hot solutions of the component sulphates in the presence of a little sulphuric acid, and after digesting for some time on the steam-bath, the crystalline products were filtered off by suction, washed with cold water and dried at 100° C. The titrations were carried out in the same way as described above in the case of the simple sulphate. It was observed that the nickel salt reacted very slowly, apparently on account of difficult solubility, while the other compounds were titrated about as readily as hydrazine sulphate alone.

The following results were obtained:

	Substance	KIO_3 used	N_2H_4 found	Calculated
$ZnSO_4(N_2H_4)_2.H_2SO_4$	·1163^g	43·2^{cc}	19·83%	19·81%
"	·0880	32·6	19·77	"
$CdSO_4(N_2H_4)_2.H_2SO_4$	·1591	51·25	17·21	17·29
"	·1396	45·10	17·25	"
$NiSO_4(N_2H_4)_2.H_2SO_4$	·0692	26·30	20·29	20·23
"	·0890	33·80	20·28	"
$CoSO_4(N_2H_4)_2.H_2SO_4$	·1308	49·20	20·09	20·20
"	·1059	39·70	20·02	"

Sheffield Scientific School,
New Haven, Conn., February, 1912.

ART. XXXIII.—*Relations of the Degree of Metamorphism to Geological Structure and to Acid Igneous Intrusion in the Narragansett Basin, Rhode Island;* by F. H. LAHEE.

(Continued from p. 262.)

PART II.

CONTENTS.

PETROLOGY OF THE CARBONIFEROUS SEDIMENTS.

INTRODUCTORY REMARKS.—Aside from the effects of metamorphism, the Carboniferous formation of the Narragansett Basin consists of a series of shaly, sandy, and conglomeratic rocks, which are notable (1) for their rapid textural variations, both parallel and perpendicular to the bedding; (2) for the abundant presence in them of such lithologic structures as local unconformity and cross-bedding; (3) for the considerable proportion of soluble clastic minerals in them; and, (4) for their content of fossil land organisms and coaly layers, with a total absence of anything marine. Although these features may be said to characterize the formation as a whole, they do not all belong to all horizons. The evidences point (1) to a prolific source of materials; (2) to the incompleteness of chemical weathering here in Carboniferous times; and, (3) to rapid deposition by stream action, partly on land and partly in standing bodies of fresh water.

After the Carboniferous strata were laid down, they were folded and metamorphosed, the original minerals being recrystallized in some cases or breaking up and recombining to form

new and entirely different minerals in other cases. Every stage in the process, almost from the beginnings of the change to the highest metamorphism, is exhibited by these sediments in different parts of the Basin.

Study of the Specimens.—In our treatment of the petrology, we shall consider the metamorphism as having four degrees, called Stages A to D. The metamorphism is incipient in Stage A; distinct, but rather low, in Stage B; considerable to high in Stage C; and at a maximum in Stage D. We shall describe in order the coals, the pelites (shales, slates, and mud schists), the psammites (sandstones, grits, arkoses, and their metamorphosed derivatives), and the psephites (conglomerates and conglomerate gneisses).

Coals.—While the coals form a very insignificant proportion of the whole stratigraphic series, they are important in that they illustrate certain principles which apply, though less clearly, to the other sediments. The least altered specimens (Stage A) are soft and friable and crumble into small regular polyhedra. There is a direction of easy splitting parallel to the bedding (primary cleavage). So slight has been the deformation that most delicately ribbed impressions of Cordaites have been hardly distorted.

With an increase in the metamorphism (Stages B and C), the rock becomes less brittle, less friable, and somewhat harder and denser. A secondary cleavage is developed, with flat or undulating surfaces, and these surfaces are often slickensided or have a bright gloss which is due to internal rock movement under pressure.

The extreme stage of metamorphism (Stage D) is found near large, massive quartz veins which, as will be explained subsequently, are abundant in certain localities. Here the secondary cleavage is extremely thin and contorted and there is a great deal of slickensiding and glazing. Chemical analyses show that, with this increase in metamorphism, the ratio of fixed carbon to volatile constituents becomes greater. The coals pass from anthracite to graphite or 'plumbago'. None of the phases are marked by the occurrence of minerals typically of metamorphic origin.

In their present condition the coal seams are far from being uniform in thickness, for the compression to which they were subjected during the folding had the effect of thinning where the strain was at a maximum and of thickening where it was at a minimum, so that they are now ribbed or 'rolled.' This distortion involved shearing and brecciation. Shearing and its consequent high degrees of metamorphism are characteristic of the thinner portions; and brecciation is more common in the thickened portions in which lower stages of metamorphism prevail.

The different phases may all occur in one locality, or even in one seam, especially in regions of varying intensity of folding (e. g., Aquidneck Island) (see fig. 21, p. 365); but where the deformation is extreme (western coast belt), only the higher stages are found. The degree of metamorphism, then, is dependent, at least in part, upon the amount and kind of deformation.

Pelites.—According to their content of carbonaceous matter, the pelites, representing original muds and clays, range in color from black to light gray or greenish. They occur chiefly in the Kingstown and Aquidneck formations. With the darker phases coal seams are often associated.

In their least metamorphosed condition (Stage A) these rocks (shales) are dull and they break with rough, irregular surfaces—usually more easily parallel to the bedding. The finer the texture and the more abundant the plant remains, the more perfect is this primary cleavage. The principal minerals, as observed with the microscope, are carbonaceous powder; quartz, in minute, angular fragments, sometimes with undulose extinction; and a very little feldspar, sericite, and ilmenite. All but the sericite are clastic in origin. There is no distinct parallelism in the arrangement of the constituents, unless it is in a streaking of the carbonaceous matter parallel to the bedding.

Low metamorphism (Stage B) is indicated megascopically by a fair secondary cleavage, by a gloss on the cleavage surfaces, due to a parallel arrangement of sericite laths, and by distortion of fossils if these are present. Microscopic examination shows the rock to have a composition similar to that of specimens in Stage A; but here the ilmenite is metamorphic in origin, as seen by its relations to the other constituents (see fig. 1), the sericite is more abundant, and a little chlorite occurs. The quartz grains have suffered more granulation and slicing, particularly in the coarser rocks, and have sometimes been squeezed out into lenticular aggregates (see figs. 4 to 10). The parallel arrangement of these elongate quartz grains and aggregates and of a large proportion of the sericite laths is the cause of the secondary cleavage. The ilmenite has no definite orientation.

In the pelites of Stage C the sericitic gloss, just described, has been enhanced in brilliancy by the richer development of this mica; the secondary cleavage is usually more perfect; and in most cases there has been anamorphic chemical rearrangement with the consequent growth of 'knots' or metacrystals.*

* A name used by Lane in reference to phenocrysts in metamorphic rocks, the metacrysts being of later origin than the groundmass. See Lane, A. C., Studies of the Grain of Igneous Intrusives, Bull. Geol. Soc Am., xiv, 369, 1903.

Under the microscope the finer portions of the rock (groundmass when metacrysts occur) display certain features different from those seen in Stage B. For instance, in addition to the straining, crushing, and slicing of the quartz, some grains are partly or wholly recrystallized (see fig. 11); that is, some of the quartz is metamorphic. Furthermore, occasionally a little secondary albite or oligoclase may be discovered; and the ilmenite individuals have grown so large and conspicuous as to be classed with the metacrysts.

Fig. 1. Fig. 2. Fig. 3.

Figs. 1–3. Progressive elongation of crystals of ilmenite accompanying increase of metamorphism. All are of secondary origin. The outlines in fig. 1 and fig. 2 and the white areas included in fig. 2 are due to quartz. The arrows indicate the direction of the schistosity.

The 'knots,' or 'knoten,' are oval granular aggregates (see figs. 13 and 14), measuring one millimeter or less in length and lying with their long axes parallel to the cleavage. They consist of quartz, chlorite, muscovite, and calcite, with a little ilmenite, rutile, and limonite. While generally lacking signs of distortion, in zones of maximum shearing their constituents have assumed positions of alignment parallel to the adjacent groundmass minerals. The cleavage of the rock curves round them. Laterally they are confined by strings of sericite; at their ends the sericite of the body of the rock gradually gives place to chlorite and muscovite, micas which are especially characteristic of these knots.

Although any of the minerals just cited may be found in any portion of a knot, there is ordinarily an obscure concentric arrangement, particularly in the least sheared forms (fig. 14). The principal constituent, quartz, predominates in the central part of the knot, and is there coarser than nearer the periphery. Just outside of the quartz core, which may also contain some calcite, rutile, etc., is an annular belt of unevenly distributed patches of calcite which encloses streaks and bunches of powdery limonite. In one instance the shape of the belt was rudely hexagonal. In another the limonite occurred in two sets of parallel streaks which crossed the core. Such features suggest pseudomorphism.

The outer peripheral portion of the knot is composed of finely granular quartz with chlorite and muscovite laths and

small ilmenite crystals. After treating a crushed knot with dilute hydrochloric acid, the residue was found to contain minute, nicely shaped crystals and reticulated aggregates of rutile about ilmenite plates.

On the whole the facts indicate that these knots represent the positions of once existing crystals of some mineral which decomposed into a pseudomorphic form and was then modified by addition of material, by recrystallization, and by mechanical rearrangement.

The metacrysts, in pelites of Stage C, named in the order of decreasing frequency, are, ilmenite, biotite, garnet, and ottrelite. They are not all found in all specimens. Generally one or two are conspicuous and the others are scarce or absent. These four minerals were formed contemporaneous with, or later than, the schistosity. Only one among them, the ilmenite, acquires parallel orientation of its crystals in Stage C (see fig. 2). Sometimes biotite has a linear parallelism such that the length of its plates are parallel, but the widths lie in all positions perpendicular to this common direction. Although isometric and therefore equidimensional, garnet is distinctly a mineral which develops under dynamic and not under static conditions. Ottrelite, which is very rare, is wholly unrelated in size, shape, and orientation, to the schistosity, and is consequently of late anamorphic derivation under static stress. The infrequent lack of dimensional parallelism in the ilmenite and the more common absence of the same in the biotite are due to the fact that these minerals, too, under such circumstances, originated under static pressure.

The most highly metamorphosed pelites (Stage D) are characterized by as large a percentage of white mica (muscovite or sericite) as the composition of the rock will permit; by a very high sheen on the fracture surfaces; and by an excellent cleavage. As seen in thin sections, the quartz grains are commonly elongate (fig. 12) and may be grouped in ribbon-like aggregates. Their shape, their clearness, their freedom from strain-shadows, and their relations to the adjacent minerals, point to the conclusion that they are secondary or recrystallized quartz. Both as single grains and as aggregates, they are oriented with their longest dimensions parallel. Together with the similarly disposed mica, they are the chief cause for the very good cleavage.

Among the metacrysts, ilmenite occurs in small plates parallel to the schistosity (fig. 3); biotite here acquires elongate habit in single plates and as aggregates, which lie with their lengths parallel to the cleavage (fig. 17); and garnet and ottrelite possess the same characters which they had in Stage C (figs. 18 and 20).

FIG. 4.

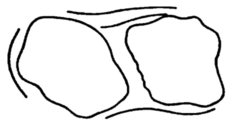


FIG. 5.

FIG. 6.

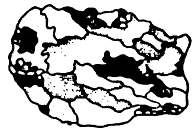


FIG. 7.

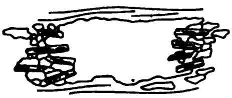


FIG. 8.

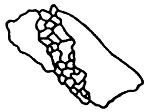


FIG. 9.

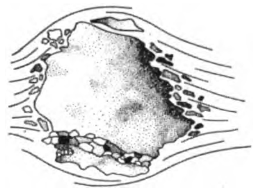


FIG. 10.

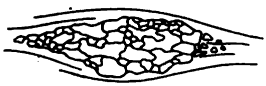


FIG. 11.

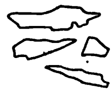
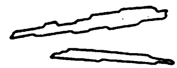


FIG. 12.



FIGS. 4–12. Changes in quartz, which accompany increasing metamorphism. In fig. 4 the grains are still uncrushed and unstrained, and display their clastic outlines. Figs. 5 and 6 show mottled extinction passing into granulation. In fig. 7 conspicuous granulation is terminal and small muscovite laths have grown a little way into the ends of the quartz grain. Fig. 8 represents zonal granulation, due to shearing. Fig. 9 shows both terminal and zonal granulation and undulose extinction. The curving lines indicate the direction of schistosity. With complete granulation, flattening, and some recrystallization, the original grains become flattened aggregates, as drawn in cross-section in fig. 10. Figs. 11 and 12 are of grains of quartz which owe their elongate shape entirely to recrystallization.

FIG. 13.

FIG. 14.

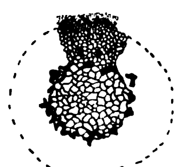


FIG. 13. 'Knot' showing elongation parallel to schistosity and distribution of sericite, thickly plastered against the sides of the 'knot,' but less abundant at its ends.

FIG. 14. 'Knot' (partly drawn), showing coarser center and ring-like arrangement of calcite patches containing limonite (black patches).

Psammites.—The psammites are the commonest rocks in the Basin formation. They occur at all horizons. As contrasted with the pelites, they are coarser, contain less carbonaceous matter, and number feldspar and muscovite among their

FIG. 15.

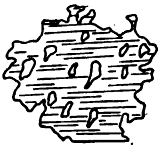
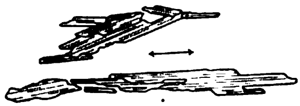


FIG. 16.

FIG. 17.



FIGS. 15–17. Changes in biotite, which accompany increasing metamorphism. Fig. 15: low metamorphism; the mica bears no relation to schistosity, which is indicated in the dimensional parallelism of included quartz grains. Fig. 16: shreds along the edges of the mica bend into parallelism with the schistosity. Fig. 17: aggregates are elongate parallel to the schistosity (arrow); the metamorphism is high.

FIG. 18.

FIG. 19.

FIG. 20.

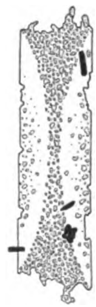


FIG. 18. Garnet metacryst: The schistosity curves round it. Secondary chlorite is developed at the poles of compression (right and left). The black patch is ilmenite.

FIG. 19. Hornblende metacryst, including quartz grains and an ilmenite crystal.

FIG. 20. Ottrelite metacryst, showing hour-glass structure (due to peculiar distribution of included quartz and carbonaceous matter of the groundmass). The black crystals are ilmenite.

original constituents. Those specimens which are least metamorphosed (Stage A) already exhibit alteration of orthoclase to sericite, but this mica has no definite alignment. Both quartz and feldspar grains still possess their clastic forms (fig. 4). Flattening of fossil casts and bending of the primary muscovite flakes are the only signs of distortion, and these are caused by superincumbent weight and not by shearing.

In many respects the succeeding stages of metamorphism in the psammites are like those in the pelites. Thus, the tokens of advancing metamorphism, as observed in Stages B to D, are (1) an increase in the quantity of sericite (here formed largely from clastic feldspar grains); (2) the acquisition of dimensional parallelism by this sericite; (3) the consequent origin of a secondary rock cleavage; (4) the transformation of fragmental quartz grains, by a process of granulation (see figs. 6 to 9) succeeding a state of mottled extinction (fig. 5), into lenticular aggregates (fig. 10) of small, somewhat elongate, parallel granules, and (5) the resulting improvement of the rock cleavage; (6) the further lengthening of the quartz grains by recrystallization (figs. 11 and 12); (7) the growth of such new minerals as ilmenite, biotite, garnet, hornblende (fig. 19), and zoisite; and (8) the acquisition of dimensional parallelism by ilmenite and later by biotite, first as aggregates (fig. 17) and then as individual plates.

These changes take place in the same order and under the same circumstances as those which were described for the pelites. Yet, on the whole, any given degree of perfection of the secondary cleavage is attained somewhat earlier in the pelites than in the psammites. There is no necessity for explaining the characters of the several stages in detail.

Psephites.—Although stratigraphically the conglomerates and their derivatives have as wide a range as the psammites, their total thickness is less. Their largest expression is in the Dighton or Purgatory conglomerate, the uppermost member of the Carboniferous formation in this region.

Consisting of both matrix and pebbles, the psephites may be studied from two standpoints; but since the matrix, in all stages of metamorphism, resembles the psammites in the same stages, we may confine ourselves chiefly to describing the nature of the pebbles. A considerable majority of these are of quartzite. Granite and vein quartz are also not uncommon, and locally, at certain horizons, there are abundant, rather angular fragments of carbonaceous shale, probably intraformational. The last are relatively soft, and therefore, as might be expected, they are somewhat compressed even in the least crushed specimens (Stage A). As usual, this early phase of metamorphism is marked by scarcity of sericite and by absence of a secondary rock cleavage.

Pebbles of Stage B differ from those of Stage A in being thinly coated with sericite, which gives a silky luster to their surfaces. At the same time there is more sericite in the matrix.

A further increase in the development of this mica is exhib-

ited by specimens of Stage C. Here the sericite occurs, not only in the matrix and plastered outside the pebbles, but also, to a certain extent, within them. Metacrysts of ilmenite, biotite, and garnet are sometimes present in the matrix. Many of the pebbles—even the more resistant ones—particularly when examined with the microscope, show signs of distortion in their own oval shape and also in the elongate form of their individual grains. If two pebbles are in contact, one often indents the other. The lengths of the pebbles and of their constituents are roughly parallel to a secondary cleavage (schistosity) which has been produced in the matrix at this stage.

In Stage D the hardest pebbles may be sheared, flattened or elongated, bent, warped, and fluted. The less resistant ones have been squeezed into mere sheets and are cleaved parallel to their flatness. Recrystallization in pebbles and matrix is at a maximum. In both parts of the rock sericite is plentiful, and the metacrysts themselves may be nearly as abundant in the pebbles as in the matrix.

The study of these phases in the psephites brought out the fact that spindle-shaped pebbles (linear schistosity) are characteristic of lower metaphorism than are flattened, sheet-like pebbles (plane schistosity). Moreover, when the matrix, as a whole, is more resistant to deformation than the separate pebbles, the pebbles first reveal evidences of incipient metamorphism, and, at any given stage in the history of the rock, they are at a stage of metamorphism somewhat higher than that of the surrounding matrix; and when the matrix is less resistant than the pebbles, the reverse of this statement is true. That is to say, deformation first affects the weaker portions of the rock.

Summary.*—The Carboniferous sediments, originally normal fresh-water clastics, which represented the products of immature weathering, have been altered by dynamic and static metamorphism. During the process certain new minerals developed. In different specimens these minerals vary in species, in quantity, in orientation, and in size of the individual particles, and it is found that the variations are consistent with, and may therefore be used to some extent as indices of, the degree of metamorphism to which the rock has been subjected. Other factors, such as perfection of cleavage, deformation of pebbles, etc., serve in the same capacity. According to these indices the specimens have been classified in groups, each of which is characterized by a particular stage of metamorphism.

* In the foregoing outline the major portion of the petrographic investigation, with all its details of megascopic and microscopic description, has been omitted. We have endeavored to present a fair, though concise, idea of the kind and amount of metamorphism, and of the method adopted in the work.

The degrees of metamorphism may now be studied with reference (1) to rock texture; (2) to geographical distribution; (3) to stratigraphic depth; and, (4) to deformation. Following this, the relations of the schistosity to the bedding, a subject closely allied to (4), just mentioned, will receive consideration.

Relations of the Degree of Metamorphism to Rock Texture.

A comparison of the degrees of metamorphism in rocks of coarse and fine grain from different parts of the Basin would be unprofitable, for many other factors might enter to disguise the true relations. Such a comparison must obviously be one of purely local significance.

Theoretically, shales, being finer than sandstones, should yield to folding first; and, since folding implies more or less rearrangement of the rock particles (deformation by flowage or by minute fracture), metamorphism should also commence first in the shales. This statement would seem to indicate that, in a series of strata which differ from one another in texture, the finer beds would be more intensely crumpled,* and hence more highly metamorphosed, than the coarser beds, after a given period of time, metamorphism being in process all the while.

What are the conditions in the Narragansett Basin? From each of twenty-two localities visited in the field work, two or more specimens of different texture were obtained. Following is a list of these specimens:

General locality Just north	Conglomerates. Stage of metamorphism	Sandstones. Stage of metamorphism	Shales. Stage of metamorphism
of C : 1	B	B	C
E : 1	A	A	—
H : 4	—	A	A
G : 5	B	B	—
C : 7	—	D	C
B : 9	C	C	C
E : 9	—	D	C
B : 11	—	C	C
C : 12	—	C	D
D : 10	—	D	D
D : 11	—	D	C
E : 11	—	C and D	C
E : 12	D	—	B

* See remarks on *competent structure* and reference thereto in Part I of this paper. This Journal, last number, p. 254.

General locality	Conglomerates. Stage of metamorphism	Sandstones. Stage of metamorphism	Shales. Stage of metamorphism
H : 13	C and B	B	—
F : 10	—	C	C
H : 10	D	—	C
J : 5	—	A	C
J : 5	—	B	A
H : 9	C	C	—
B : 14	—	D	C
D : 14	D	—	C
G : 14	C	—	B

According to this table, (1) there are thirteen cases of like metamorphism in specimens of different texture; (2) there is one case of conglomerate having higher metamorphism than sandstone; (3) there are four cases of conglomerate having higher metamorphism than shale; (4) there are seven cases of sandstone having higher metamorphism than shale; and (5) there are two cases of shale having higher metamorphism than sandstone. Thus, out of twenty-seven comparisons, there are only two instances of the finer rock having the greater metamorphism. The same lack of concordance between fact and theory was also frequently observed in the field.

As for the explanation of this condition, while we realize that the definition of degree of metamorphism, as used in this paper, is wholly arbitrary and that the opportunity for error in assigning such degrees is therefore considerable, we believe that the general conclusion which may be drawn will still remain unmodified. Since the Purgatory conglomerate, the uppermost member of the Carboniferous formation in this region, shows evidence of intense metamorphism in the zone of flow, it is clear that all these rocks must have been under a very thick cover at the time of their deformation. Probably adjacent beds, measuring but a few feet in thickness, are not affected with very marked differentiation according to texture, under the great pressures existing at such depths. Shearing is as apt to occur in a sandstone as in a shale. Moreover, as has been stated by Daubrée* and by Harker,† more heat is developed by friction in the interstitial movements of coarse rocks than in those of fine-grained rocks, and such heat no doubt assists in the metamorphic processes.

We infer, then, that, in single outcrops, differences of texture have little or no direct influence upon the distribution of the degrees of metamorphism in those outcrops.

* Daubrée, A., Synthetical Studies and Experiments on Metamorphism. Translation by T. Egleston. Smith. Inst., An. Rept., pp. 463–465, 1861.

† Harker, A., On Slaty Cleavage . . . . Brit. Assoc. Adv. Sci., Rept., p. 848, 1885.

FIG. 21.

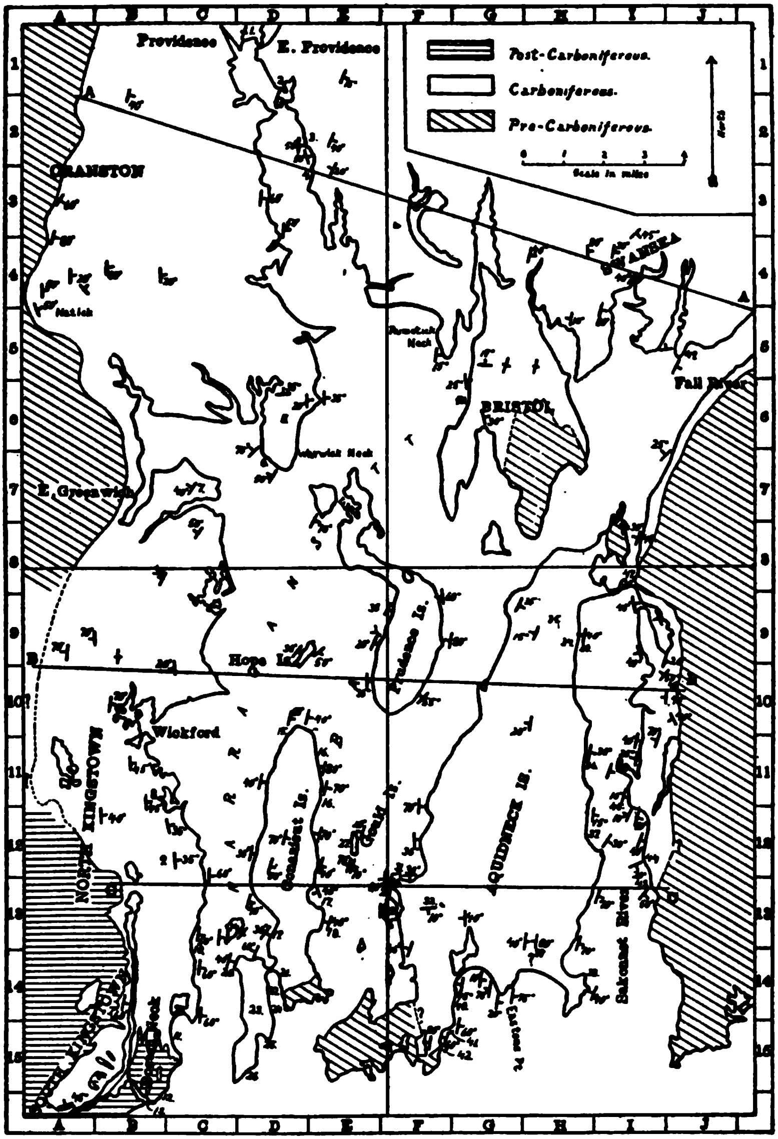


FIG. 21. Outline map of the southern half of the Narragansett Basin. Many of the dips and strikes are somewhat generalized. References to numbered localities will be found in the text.

Geographical Distribution of the Degrees of Metamorphism.

Some investigators in this region have noticed differences in the intensity of metamorphism in passing across belts two or three miles in breadth. Dale observed that the Carboniferous strata have been more metamorphosed on Conanicut and Dutch islands than in southern Aquidneck Island.* Foerste showed that the rocks of Prudence Island are less altered than those of Hope Island.† And both Foerste‡ and Collie§ remarked upon the increase in metamorphism westward across northern Conanicut Island. In our field studies we have found a like advance in metamorphism eastward and westward from the middle north-south strip of the western coast belt north of East Greenwich; southward, in the western coast belt, south of Wickford; and eastward, from Aquidneck Island to the eastern coast belt. These variations are not uniform and, in some cases, are not very conspicuous.

Of more importance is a study of the distribution of the degrees of metamorphism in the Basin as a whole. This we have done graphically as follows: The position of the eight hundred or nine hundred specimens examined was plotted on the map. For each of these, the kind of rock (coal, shale, sandstone, or conglomerate) was indicated by a symbol, and the stages of metamorphism (A, B, C, and D) were shown by four different colors. The map was then divided into four equal rectangles, as in fig. 21, and the allotment of the specimens determined. The results are tabulated below.

	Conglomerate	Sandstone	Shale	Coal	Totals
NE. rectangle :					
Stage A :	0	0	3	0	3
Stage B :	2	8	4	0	14
Stage C :	0	2	2	0	4
Stage D :	0	0	0	0	0
Totals :	2	10	9	0	21
NW. rectangle :					
Stage A :	2	5	1	1	9
Stage B :	1	2	1	0	4
Stage C :	4	6	2	1	13
Stage D :	0	1	1	0	2
Totals :	7	14	5	2	28

* Dale, T. N., The Geology of the Mouth of Narragansett Bay. Proc. Newport Nat. His. Soc., Doc. 3, 1884, p. 6.

† Shaler, N. S., Woodworth, J. B., and Foerste, A. F.: Geology of the Narragansett Basin. U. S. G. S., Monog. xxxiii, 1899, p, 241.

‡ Ibid., p. 230.

§ Collie, G. L., Geology of Conanicut Island, R. I. Trans. Wisc. Acad., x, 1894–1895, pp. 201, 217.

	Conglomerate	Sandstone	Shale	Coal	Totals
SE. Rectangle :					
Stage A :	0	2	5	0	7
Stage B :	2	9	6	1	18
Stage C :	10	5	10	1	26
Stage D :	2	0	1	0	3
Totals :	14	16	22	2	54
SW. Rectangle :					
Stage A :	1	1	1	0	3
Stage B :	0	0	2	0	2
Stage C :	5	7	14	1	27
Stage D :	3	14	13	0	30
Totals :	9	22	30	1	62

The relative number of examples of each stage for each rectangle may be calculated on a percentage basis:

Rectangle	Stage A	Stage B	Stage C	Stage D	Total
NE.	14·286%	66·667%	19·047%	0%	100·00%
NW.	32·143	14·286	46·428	7·143%	100·00
SE.	12·963	33·333	48·148	5·555	100·00
SW.	4·918	3·279	42·623	49·180	100·00

Grouping Stages A and B (rather low metamorphism) together, and Stages C and D (rather high metamorphism) together:

Rectangle	Stages A and B	Stages C and D
NE.	80·953%	19·047%
NW.	46·429	53·571
SE.	46·296	53·704
SW.	8·197	91·803

These figures demonstrate plainly that the degree of metamorphism in the southern half of the Basin increases westward and southward.*

Relations between the Degree of Metamorphism and Stratigraphic Depth.

This subject may be approached in two ways: we may study specimens brought up from known depths in borings or in mines, or we may examine surface outcrops of which the stratigraphic position is at least fairly certain.

(1) In regard to the first suggestion, Professor Woodworth† cited the statement of Professor Collier Cobb, that "the

* We have already suggested that the western coals are most highly metamorphosed. See p. 356.

† Shaler, N. S., Woodworth, J. B., and Foerste, A. F.: op. cit., p. 191.

amount of metamorphism varies with the depth, being greater at the bottom (of bore-holes) than near the surface." Cobb drew this conclusion from his study, in 1887, of a set of cores obtained from two bore-holes in Portsmouth, R. I. (near Loc. 34, H : 9, fig. 21). We have made a thorough re-examination of the same cores with the following results :

Hole 1			Hole 2		
Actual depth	Rock	Stage of metam.	Actual depth	Rock	Stage of metam.
			13′ 1″	Coarse sandstone	A
			36′ 7″	Medium "	C
			92′ 8″	" "	A
			102′ 1″	" "	A
			114′ 2″	Coarse "	A
			129′ 3″	Fine, dark shale	A
			149′ 3″	Medium sandstone	B
286′ 11″	Fine, dark shale	C	194′ 7″	Banded shale	A
109′ 10″	" " "	A			
			233′ 2″	Medium sandstone	A
244′	" " "	B			
			284′ 7″	" "	B
			325′ 11″	Coarse shale	A
			334′ 4″	Medium sandstone	A
336′ 10″	Fine sandstone	B			
			380′ 3″	Coarse sandstone	A
484′ 4″	Coarse shale	C			
567′ 4″	" "	C			

In Hole 1, if it were not for the first mentioned shale, the metamorphism would show a regular increase downward ; but this specimen proves that high metamorphism is not necessarily limited to great depth in the Basin.

In Hole 2 there is practically no alteration from top to bottom. An exception occurs at 36′ 7″, where the highest metamorphism in the boring is recorded.

Although the data furnished by these specimens are scanty, nevertheless the facts which they set forth are not to be disregarded. They indicate (1) that, at least as low as 400 feet, depth has no obvious effect upon the intensity of the metamorphism, and (2) that a high degree of alteration may occur near the surface and at considerable depths alike.

(2) According to the interpretation of the structural geology, strata in the Wickford district are at about the same horizon as those of the Bonnet ; yet the metamorphism is more intense in the latter region. The rocks of Dutch Island (Loc. 14, C–D : 13, fig. 21), Beaver Head (Loc. 20, C–D : 14), and west-

ern northern Conanicut, are stratigraphically lower, and are more metamorphosed, than those of northeastern Conanicut. In northern Aquidneck Island, the rocks of the eastern and western coasts are below those of the central portion of the island; but the eastern outcrops display more alteration than do the middle and western outcrops. The conglomerate of High Hill Point (Loc. 45, 1: 11–12), correlated with the Purgatory conglomerate of southeastern Aquidneck, is more highly sheared than the latter. Finally, the arkose and associated rocks, which are presumably low in the series, are scarcely metamorphosed on the eastern coast of Mackerel Cove (Loc. 22, D: 14), and are not severely crushed on Sachuest Neck (H: 14).

These and other comparisons which might be made, compel us to believe that the degree of metamorphism is not intimately dependent upon stratigraphic depth. As in the case of texture, this may be on account of the great thickness of the overlying cover during the process of metamorphism, by virtue of which differential values were reduced.

Relations Between the Degree of Metamorphism and the Intensity of the Folding.

In describing the structural geology, we discussed strikes, dips, pitch, axial planes, relative number of folds across the Basin, and minor folding.* The degree of metamorphism may now be studied with reference to each of these topics.

Strikes.—The most regular strikes were said to occur in the western coast belt on Boston Neck and northward to Barber's Height (Loc. 9, B–C: 12) and in northern Conanicut Island; and the fact was explained by the inference that the action of the maximum component of the forces of deformation was here predominant. These are also districts of almost uniformly high metamorphism.

In the western coast belt between Hamilton (Loc. 8, B: 11) and East Greenwich, and on Prudence Island, strikes are somewhat variable. The degree of metamorphism is constant and is high in these areas.

Elsewhere strikes are less regular and, coincidently, variations in the metamorphism within short distances are greater.

Thus, there seems to be a correspondence between the degree of regularity in the strikes of the major folding, on the one hand, and the intensity of the metamorphism, on the other hand.

Dips.—The degree of metamorphism is more often high than low where dips are steep; but locally it may be high in outcrops with a gentle dip.

* This Journal, last number, pp. 256–259.

Pitch.—The stage of metamorphism has no bearing upon the direction of pitch. It is usually high in regions where the pitch is steep, and may be high where pitch is low.

Axial planes.—The intensity of metamorphism is unrelated to the direction of dip of the axial planes.

Relative number of folds across the Basin.—In treating this subject, we concluded "that the number of principal folds per unit of Basin width, and therefore the degree of compression, regularly increases southward."* As regards the geographic distribution of the degrees of metamorphism, we stated "that the degree of metamorphism in the southern half of the Basin increases westward and southward" (see p. 15). Clearly, here is concordance of phenomena.

Minor folding.—Below are listed the localities of contortion† in an order such as to emphasize their positions in the major folds and to bring out the relations between the degrees of metamorphism and the amount of contortion:

Position in fold	Locality number	Metamorphism in general	Stages of metamorphism in hand-specimens			Degree of contortion
			Cg.	Ss.	Sh.	
In axial	4	Moderate	..	..	..‡	Moderate
regions of	16	High	C	D	C	Considerable
anticlines	27	"	D	..	C	High
	33	Considerable	C	C	C	"
Situated on	10	High	..	D	..	Considerable
limbs of	14	"	..	..	D	High
folds	15	"	..	D	D	"
	20	"	D	..	D	"
	48	"	..	..	..	"
Position in	1	High	..	..	..	High
folds	5	Slight	..	..	..	Slight
uncertain	6	Low	..	B	A	Considerable
	7	High	..	D	C	"
	11	"	D	D	..	"
	12	"	..	D	..	"
	13	"	..	D	..	"
	18	"	..	..	C	"
	19	"	..	..	..	"
	21	"	..	..	..	"
	22	"	..	..	D	"
	25	"	..	..	..	"
	26	"	..	..	D	"
	29	Considerable	..	..	..	"

* See this Journal, last number, p. 259. † Ibid., p. 259.

‡ Wherever there is no record in this column, the data were obtained in the field only.

30	Moderate	..	B	..	Moderate
36	Considerable	..	..	C	Considerable
37	Low	..	..	A	Moderate
38	Moderate	..	B	..	Considerable
40	"	C	B	B	"
41	"	..	..	B	Moderate
44	Considerable	C	..	..	High
49	Variable	..	C	A	Variable
50	Moderate	..	B	..	Moderate

This table indicates a close dependence of the intensity of metamorphism upon the degree of contortion. Whether the outcrops are situated on the limbs or in the axial regions of major folds appears to make no difference.

Relations of the Schistosity to the Bedding.

In a majority of the outcrops examined the schistosity was nearly, if not quite, parallel to the stratification.* However, while this is true of the coarser rocks, it does not so often hold for the pelites. Very notable exceptions are frequent in the greenish schists of southern Conanicut Island.

Linear schistosity, when well developed, may trend parallel to the strike of the beds, or parallel to their dip, or in some other direction. Most often, perhaps, it coincides with the strike. This relation is not commonly evident in the psammitic and pelitic rocks on account of their fine texture; but in the conglomerates it is easily discerned in the attitude of the elongated pebbles.† The data obtained in the field work prove that parallelism with dip or strike is generally in regions where the strikes are uniform (western coast belt, southern Aquidneck Island), and that departures from this relation are

* Collie (op. cit., p. 213) described this for Conanicut Island, and inferred that the "schistosity was developed pari passu with the tilting of the rocks, and that both processes were due to dynamic pressure."

† The lengths of distorted pebbles in metamorphosed conglomerates have been recorded as parallel to the strike of the beds, by H. H. Reusch (Die Fossilien Fuhrenden Krystallinischen Schiefer von Bergen in Norwegen. German translation by R. Baldauf. Leipzig, 1883. Pp. 52-53); Ed. Hitchcock (Final Report on the Geology of Mass. Amherst and Northampton, 1841. P. 535; and also, On the Conversion of certain Conglomerates, etc., this Journal (2), xxxi, 372. 1861. P. 384); and W. O. Crosby (Contributions to the Geology of Eastern Mass., Bos. Soc. Nat. His., Occas. Papers, 1880. Pp. 148–149). On the other hand, the case in which the pebbles lie lengthwise parallel to the dip has been described by Ed. Hitchcock (On the Conversion of certain Conglomerates, etc. Loc. cit., p. 380); C. H. Hitchcock (General Report upon the Geology of Maine; in the Sixth Ann. Rept. of the Secretary of the Maine Board of Agriculture, 1861. P. 132); and W. P. Blake (The Plasticity of Pebbles and Rocks: Proc. Am. Assoc. Adv. Sci., xviii, p. 199. 1869. P. 201). These differences are caused, no doubt, by the diversity of orientation of the maximum, intermediate, and minimum values of complex forces during deformation.

especially characteristic of districts in which the dips and the strikes are variable. As illustrating the latter case may be mentioned the area north and northeast of Warren Neck, i. e., the southern nose of the great Swansea syncline.

On the whole, the attitude of the schistosity in different portions of the Basin is closely related to the attitude of the stratification.

Conclusions.

Following are the conclusions arrived at from the study of the Carboniferous rocks of the Basin:

1. During the period of their deformation, the Carboniferous sediments were deeply buried.

2. On account of the thick cover, or for other reasons, variations in the degree of metamorphism have been directly determined neither by alternating differences of texture nor by relative stratigraphic depth.

3. The degree of metamorphism is closely related to the kind and intensity of the folding, for (*a*) metamorphism and compression increase in severity in a southward direction; (*b*) the greatest metamorphism occurs in the region where there is greatest regularity of strikes; (*c*) contortion of the beds is accompanied by a high degree of metamorphism; and, (*d*) the attitude of the schistosity generally bears a close relation to the attitude of the bedding.

Cambridge, Mass., Feb. 1, 1912.

(To be concluded.)

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Separation of Titanium from Niobium, Tantalum, Thorium, and Zirconium.*—It has been found by J. H. Muller that salicylic acid shows a different behavior with titanium hydroxide than with the other "metallic acids." An excess of salicylic acid added to alkaline niobate or tantalate solutions completely precipitates the acids, but the presence of an alkaline fluoride prevents this precipitation. Orthotitanic acid dissolves in salicylic acid, giving, in the absence of fluorides, an intensely yellow solution. Zirconium and thorium hydroxides dissolve with difficulty in salicylic acid, but after ignition the resulting oxides are practically insoluble in it.

Known amounts of the oxides of niobium, tantalum, zirconium and thorium were each mixed with known weights of titanic oxide, and the mixtures were then fused with 5 grams of potassium carbonate, the fusions were taken up in 350–400^{cc} of water at 60° and treated with 14–15 g. of salicylic acid, and heated for 3 or 4 hours at the boiling temperature. Then the precipitates were allowed to settle, filtered rapidly, and washed with boiling water. The concentrated filtrates were treated with ammonium hydroxide, when titanium was precipitated, washed and ignited to oxide. The precipitates were invariably contaminated with alkali salicylates which could not be removed by washing. The ignited oxides were, therefore, fused with potassium bisulphate and weighed in the usual manner.

The results given from test-analyses show remarkably good results in the separation of elements which has heretofore been exceedingly difficult or even impossible in some of the cases. From the tabular statement of the results it appears that three or four fusions are necessary with any but very small amounts of titanic acid, although nothing is said about this point in the description of the method.

The exceedingly strong color of the salicylic acid solution of titanic acid was used satisfactorily in determining the titanium in several mixtures, but the author considers this calorimetric method as of little practical value, owing to the interference of the common contaminants of titanic oxide.—*Jour. Amer. Chem. Soc.*, xxxiii, 1506. H. L. W.

2. *Cementite.*—This important constituent of steels, Fe_3C, which may be called also tri-ferro-carbide, has recently been carefully studied by Ruff and Gersten with interesting results. The substance was prepared according to well known principles by suddenly cooling molten iron saturated with carbon and treating the pulverized product at first for a long time with dilute acetic acid, then pulverizing the residue and treating it further

with 1/5 normal hydrochloric acid, and finally after removing material of low specific gravity by stirring and decantation, washing with alcohol and ether and drying in a vacuum. The material thus prepared appears to have been unusually pure, as it was crystalline in character, gave analytical results very close to those required by theory, and contained no graphite. The product was dark gray with a tint of bronze in some cases, and very brittle. Some of the larger fragments were used for hardness determinations with the surprising result that this was found to be only just above 3, according to the mineralogical scale. The conclusion is reached, therefore, that it is not the hardness of the carbide itself which causes the hardness of suddenly cooled steel, but that of its solid solution in γ-iron.

The authors have determined the heat of combustion of their product and have found 375·1 cal. per molecule of Fe_3C, when burnt to Fe_3O_4 and CO_2. By comparing this result with their own determinations of the heat of combustion of pure iron and the known value for graphitic carbon, they have calculated the heat of formation as follows:

$$3Fe + C = Fe_3C - 15{\cdot}1 \text{ cal.}$$

The compound is consequently shown to be endothermic, whereas previous indirect calculations had indicated an exorthermic combination of +8940 cal.—*Berichte*, xlv, 63. H. L. W.

3. *The Use of Sulphur Monochloride for Decomposing Certain Minerals.*—The process of decomposing various minerals by means of sulphur monochloride was described by Edgar F. Smith in 1898. Since that time the method has been applied by various other chemists. W. B. Hicks, of the University of Pennsylvania, has recently applied this method to the decomposition of fergusonite, æschynite and samarskite, which are rare-earth minerals containing columbium and tantalum. The process consists in heating the finely pulverized mineral in a boat in a combustion-tube in contact with the vapor of sulphur monochloride, with the result that columbium, tantalum, titanium and tungsten are volatilized as chlorides and may be collected in nitric acid, while the rare earths, together with silica, are left behind in the boat. The method appears to possess advantages over the usual methods of decomposition by means of fusion with acid potassium sulphate or the acid fluoride.—*Jonr. Amer. Chem. Soc.*, xxxiii, 1492.

H. L. W.

4. *Determination of Water.*—Zerewitinoff has devised a rapid and accurate method for the determination of water in various substances, which is interesting on account of being based on a new principle. He treats the substance, for example coal or starch, in a special form of apparatus with perfectly dry pyridine. This liquid is very hygroscopic and, therefore, takes up the water from the substance. A proper amount of methyl magnesium iodide in amyl ether solution is then added whereby methane is liberated, and the volume of this gas is at once meas-

ured in the special apparatus, and from this gas volume the weight of water present is calculated. The reaction taking place is as follows:

$$2CH_3MgI + H_2O = 2CH_4 + MgI_2 + MgO.$$

For the preparation of the reagents, which requires special precautions, as well as for the description of the apparatus, the measuring part of which is based upon Lunge's nitrometer, reference must be made to the original article.—*Zeitschr. analyt. Chem.*, li, 680. H. L. W.

5. *Reduction of Vanadic Acid in Concentrated Sulphuric Acid Solution.*—Cain and Hostetter have found that vanadium pentoxide in concentrated sulphuric acid solution is reduced immediately and quantitatively to the quadrivalent condition by hydrogen peroxide. All that is necessary is to evaporate the solution until fumes are given off freely, cool, add a slight excess of 3 per cent hydrogen peroxide, cover the flask and fume strongly for a few minutes to destroy the excess of hydrogen peroxide, after which the solution may be titrated with permanganate. It was found that molybdenum, titanium and iron are not similarly reduced, and that persulphates and also Caro's acid have the same effect as hydrogen peroxide upon the vanadium pentoxide.—*Jour. Amer. Chem. Soc.*, xxxiv, 274. H. L. W.

6. *Die Zersetzung von Stickstoffdioxyd im elektrischen Glimmstrom.*—An easily reproducible, beautiful and instructive demonstration experiment was performed by J. Zenneck before the Physical Section of the 83d Convention of German Scientists at Karlsruhe, on September 26, 1911. The apparatus was constructed of glass, and it may be described as follows.

A cylindrical bulb with its long axis vertical was partly filled with pure nitrogen tetroxide, N_2O_4, which was maintained in its more complex molecular condition and liquid state by surrounding the bulb with a freezing mixture of ice and common salt. A horizontal glass tube of convenient diameter connected the top of the bulb with a discharge tube, to be described later on. The horizontal tube was drawn down to capillary dimensions not far from its union with the bulb. Beyond the capillary section this tube was provided with a glass stopcock. The discharge tube was shaped like a vertical U, with relatively long "legs" or parallel branches which were comparatively close together. Near the upper end of each leg a short, horizontal section of glass tubing was sealed in place. These inlet and outlet tubes were at the same level and both were situated in the plane of the U-tube. The object of these tubes was to enable the experimenter to connect the discharge tube with the above-mentioned horizontal tube leading from the bulb, and with the rest of the train of apparatus, by means of short pieces of rubber "connecting tubing." Above the common level of the horizontal tubes each leg of the U-tube was sealed to a vertical, cylindrical bulb. Each bulb contained an electrode whose wire was sealed into the top of

the bulb and then continued to one terminal of the secondary of a spark coil. The primary coil was fed with an alternating current. Thus the discharge tube was simply a long vacuum tube bent through 180° at the middle of its length. The outlet tube was joined to a second discharge tube which was spherical in form and which was provided with two lateral tubes each containing one electrode. These side tubes were in the same vertical line and hence at right angles to the several sections of connecting tubing. The inlet and outlet tubes of the spherical discharge bulb lay along a horizontal diameter, and each was furnished with a glass stop-cock. The last outlet tube led to a Gaede mercury pump. Usually the pump was regulated so as to maintain a pressure of about 1^{mm} of mercury in the region of the inlet of the U-tube, and this corresponded to a rate of flow of the gas of about 8 meters per sec., at the same place.

When all three cocks were open and the U-tube alone was suitably excited, the following striking phenomena could be observed. Just below the inlet tube the discharge was yellow with a tinge of orange, and this was succeeded by a bluish violet region lower down in the limb. Still further down in this branch and throughout the entire curved portion of the U a greenish yellow light was emitted. In the second leg, and immediately below the outlet tube, the gas radiated bright red. If the electric current was decreased, while the flow of gas was maintained constant, the regions of different hues grew appreciably longer. Increasing the current shortened the colored segments. On the other hand, when the electrical conditions were kept invariable, the aforesaid regions increased or decreased in length according as the rate of flow of gas was made larger or smaller.

That these phenomena are due to successive stages in the dissociation of nitrogen dioxide may be shown by the aid of the spherical discharge tube. Without exciting either tube, the gas is drawn slowly through the entire system for some time, and then the cocks on both sides of the spherical bulb are closed. On sending the electric current through this bulb the discharge first assumes a reddish yellow color, which gradually passes over into bluish violet. Suddenly the color changes to greenish yellow and this, in turn, slowly gives place to bright red. Thus the various stages of dissociation which are seen simultaneously, but spread out linearly, in the U-tube are presented in succession, but in the same general region, in the closed vacuum bulb.

The question of the physical significance of the various color changes has been investigated spectroscopically by J. Zenneck and B. Strasser.* The first spectrum, of orange yellow color, belongs either to the tetroxide or the dioxide of nitrogen, since both of these vapors seem to give practically the same radiation. The second spectrum is due to some "labile" oxide intermediate between the dioxide and nitric oxide, perhaps nitrogen trioxide. Nitric oxide gives rise to the third spectrum, while the fourth is

* Phys. Ztschr., No. 26, p. 1201, Dec., 1911.

chiefly due to nitrogen and oxygen gases separately.—*Verh. d. deutsch. phys. Gesellsch.*, No. 21, p. 953, 1911. H. S. U.

7. *The Mechanism of the Semi-permeable Membrane, and a New Method of Determining Osmotic Pressure.*—Heretofore, the semi-permeable membranes used in measuring osmotic pressures had to fulfil the condition of rigidity, either directly or by being deposited in a rigid support. A very ingenious scheme for abolishing this difficult requirement has been devised and tested by F. T. Trouton. Although the principles involved are of a general nature, it will be conducive to clearness to restrict the following explanation to a typical case.

Suppose the problem is to find the value of the osmotic pressure of an aqueous solution of pure sugar of a given concentration. For theoretical purposes, we may imagine a rectangular glass vessel, of the type often used in stationary storage cells, separated into two compartments by a vertical, transverse, impervious diaphragm, *e. g.*, a sheet of glass. This diaphragm must not extend to the level of the top of the vessel. One compartment is nearly filled with water, and the other with sugar solution. These liquids are then placed in hydrostatic communication by having superposed upon their upper surfaces a layer of liquid ether of sufficient depth to completely submerge the upper edge of the partition. Since sugar is insoluble in ether, while ether dissolves a small percentage of water, it follows that the layer of ether will take the rôle of the usual effectively rigid, semi-permeable membrane. In fact, this is the key-note of Trouton's innovation, namely, to substitute a liquid semipermeable partition for a rigid one. To be sure, both water and sugar solution take up some ether, but this complication is not serious since it can be relegated to the sphere of determinate corrections. Ether dissolves about 1·05 per cent of water when placed in contact with the same, but ether absorbs less than this from a sugar solution, the amount depending upon the concentration of the solution. For equilibrium at the water-ether surface the ether must, therefore, contain 1·05 per cent of water, while at the solution-ether interface a smaller quantity is necessary to establish equilibrium. Diffusion through the ether prevents this equilibrium from being established, consequently, water will pass across from the water side to the solution side of the partition. If the ether could rigidly maintain its position so as to prevent any increase in the volume of the sugar solution, the hydrostatic pressure of this solution would increase, due to the accession of water. Under these ideal circumstances the process would come to an end when, owing to the increase of pressure, the percentage of water absorbed by the ether from the sugar solution attained the same value as the fraction of pure water taken up by the ether at atmospheric pressure. The pressure competent to effect this state of equilibrium in the ether would be the equivalent of the osmotic pressure of the sugar solution.

Effective rigidity can be imparted to the ether by the apparatus designed by Trouton and used by Burgess. It consisted of a vertical, copper U-tube strong enough to withstand an internal pressure of more than 100 atmospheres in excess over the outside atmospheric pressure. One of the parallel branches of the tube was permanently connected with a pressure gauge, and the upper ends of both branches were provided with stopcocks and inlet tubes. In charging the apparatus the first step was to introduce enough sugar solution to half-fill the tube. Then ether was sucked into the branch which was not directly associated with the gauge, and the cock closed. Next, air was pumped into the other branch of the U-tube until the gauge registered the desired pressure, after which the second cock was closed. After sufficient time had elapsed for the ether to take up its full complement of water from the solution, the cock of the branch containing the ether was opened, thus allowing the compressed air in the other branch to force the ether out into the auxiliary testing tubes. The water content of the ether was determined by passing the moist ether, as vapor, through calcium chloride drying tubes which were maintained at 40° C. "This was sufficiently warm to prevent ether condensing in the tubes, and yet was found not to be too high for substantially absorbing all the water." This entire process was repeated at different pressures, so that all the necessary data were obtained for plotting a curve having for the abscissas of its points, pressures in atmospheres, and for the ordinates, percentages of water absorbed by the ether. For a concentration of 600 grams of sugar per liter of solution the aforesaid percentages increased from 0·939 to 1·143 as the pressure changed from 1 atmosphere to 110·5 atmospheres. The curve is somewhat convex towards the pressure axis. At about 79 atmospheres the per cent of water taken from the sugar solution by the ether was read off from the curve as 1·055, which is numerically the same as for the absorption of water by ether at a pressure of *one* atmosphere. Consequently, the osmotic pressure equals 79 atmospheres. Interpolating for the given concentration from the curves of Lord Berkeley and Mr. Hartley, the osmotic pressure as determined by the ferrocyanide of copper method was found by Trouton to be 81 atmospheres. The agreement is quite satisfactory in view of the fact that Trouton has not yet attempted to perfect his method, and to take into account all necessary corrections for variations in temperature, in concentration, etc.—*Proceedings Roy. Soc.*, lxxxvi, p. 149, Jan., 1912. H. S. U.

8. *Note on the Monatomicity of Neon, Krypton and Xenon.*—Having at his disposal relatively large quantities of pure neon, krypton and xenon, and being of the opinion that the monatomicity of these gases had been taken for granted on somewhat insufficient evidence, SIR WILLIAM RAMSAY has quite recently determined γ, the ratio of the specific heat at constant pressure to that at constant volume, for each of these gases. The apparatus used was of the same type as the one described in the mono-

graph on argon,* the experimental process consisting essentially in comparing the wave-length of sound in each rare gas with the wave-length in air for the same frequency, by Kundt's method. The mean values of the wave-lengths for air, neon, krypton and xenon at 19° C. were found to be $5{\cdot}584^{cm}$, $7{\cdot}220^{cm}$, $3{\cdot}626^{cm}$ and $2{\cdot}864^{cm}$ respectively. Taking the densities of these gases, in the order named, as 14·479, 10·10, 41·46 and 65·11, and assuming γ equal to 1·408 for air, it follows that the ratio of the specific heats of neon, krypton and xenon equals respectively 1·642, 1·689 and 1·666. Ramsay concludes :—"These numbers approximate within the limits of experimental error to the theoretical ratio 1·667, and it therefore follows that neon, krypton, and xenon, like helium and argon, must be regarded as monatomic." "Their molecular and their atomic weights are identical."—*Proceedings Roy. Soc.*, lxxxvi, p. 100, Jan., 1912. H. S. U.

9. *Modern Microscopy;* by M. I. CROSS and MARTIN J. COLE. Fourth edition, revised and enlarged. Pp. xvii, 325, with 113 figures and 6 plates. Chicago, 1912 (Chicago Medical Book Co.).—"In the preparation of this new edition, the original intention that it should be for beginners and students has been steadily kept in view." The volume is divided into three parts, of which the first deals with microscopes and auxiliary apparatus such as ray-filters, artificial sources of light, text-books, etc. Care is taken to define and explain the significance of many optical terms, for example, aplanatism, chromatic over-correction, spherical aberration, etc. In short, this Part, which comprises 136 pages, will enable an intelligent beginner to purchase wisely and to subsequently use and care for his apparatus to best advantage.

Part II, of 82 pages, is devoted to staining, section cutting and, in a word, to the general preparation of microscopic objects.

Part III, covering 100 pages, is entirely new, and it is divided into seven chapters, each of which was written by a specialist. It gives information on many subjects in which amateur microscopists in particular are interested, such as : interference figures of arragonite, larvae of hydrachnid parasites, bacillus anthracis, etc. The six plates belong to this Part and they are clear, beautiful reproductions of the original negatives. In conclusion, the subject is presented in such an attractive and elegant manner that the book deserves to win many converts to the branch of science with which it deals. H. S. U.

10. *Laboratory Problems in Physics;* by FRANKLIN T. JONES and ROBERT R. TATNALL. Pp. ix, 81. New York, 1912 (The Macmillan Co.).—This book is in part a liberal revision of Crew and Tatnall's "Laboratory Manual of Physics" and, with regard to its contents, the authors say : "While these exercises may be used in connection with any text-book, the order adopted is that of Crew and Jones's 'Elements of Physics.'" The 72 experiments suggested are intentionally of an elementary nature, they

* Phil. Trans., A, 1895, Vol. 186, Part I, p. 228.

cover all of the usual subdivisions of physics, and they seem to be well arranged and wisely selected. The description of each exercise is presented under the subtitles: "Problem, Apparatus, Experiment, and Application." In most cases, the paragraphs under "Experiment" include a well-drawn diagram of the apparatus and a blank tabular form to indicate a systematic plan for recording the numerical data. The "Application" is a noteworthy feature of the volume and, in each case, it comprises several pertinent questions to be answered by the student. For example, in the case of the pendulum, one question is this:—"A block of stone, just swung clear of the ground by a derrick at the top of a high building, is observed to make one complete swing in 15 sec." "How high is the building?" The last four pages of the book are devoted to the metric system and to a table of 16 "Useful Numbers," such as:—"10 The specific heat of ice is about 0·505." The typographical errors are few and unimportant. On the whole, the book seems admirably adapted to subserve the purposes of the authors. H. S. U.

11. *Storage Batteries;* by HARRY W. MORSE. Pp. 266, with 106 text-figures. New York, 1912 (The Macmillan Co.).—This book does not contain a preface, but the author's aim and object may be inferred from the last paragraph of the introductory chapter, which reads:—"The following chapters are based on lectures which have been given for the last few years at Harvard University." "In the course the work on storage cells is preceded by study of the general theory of galvanic cells, and the simplest of this theory has been included in this book." "No attempt has been made to give any of the detail of storage battery engineering, but only to introduce the reader to the peculiarities of the cell itself."

The author possesses the happy faculty of presenting his subject in an easy and entertaining style without sacrificing logical sequence and scientific accuracy and thoroughness in the least. Thus, it is rather attractive to read of "the heyday of galvanic cells" and of "a unique battery which harks back to the earliest form." The curves and diagrams are well-drawn and to the point, and the text abounds in solutions of typical numerical examples. Finally, the treatment is well-balanced, since neither the physical nor the chemical aspect of the subject is given undue prominence. H. S. U.

12. *A Laboratory Manual of Physics and Applied Electricity;* arranged and edited by EDWARD L. NICHOLS. Vol. I. Junior Course in General Physics; revised and rewritten by ERNEST BLAKER. Pp. xiii, 417; with 135 figures. New York, 1912 (The Macmillan Co.).—The excellence of the first edition of this book has already been pointed out in this Journal, (see vol. xlviii, 346, 1894). The revised edition of this manual differs very appreciably in several respects from the earlier publication. As indicated above, it has been almost entirely rewritten. Changes have been made in the treatment of many of the experi-

ments retained, a few have been omitted, and about forty new experiments have been incorporated. In addition to the tables of natural functions, which are common to both editions, 18 tables of physical and mathematical constants have been placed near the end of the new volume. As a consequence of all these mutations the manual has expanded from 294 to 417 pages. If possible, the quality of the book has kept pace with its increase in scope. H. S. U.

13. *Die Bearbeitung des Glases auf dem Blasetische;* by D. DJAKONOW and W. LERMANTOFF. 2d edition. Pp. xv, 196, with 34 text-figures. Berlin, 1911 (R. Friedländer & Sohn).—The real author of this manual is Lermantoff, since he had as a nucleus for the first edition, which appeared in 1895, only a few fragmentary notes left by Djakonow, who died in 1888. Lermantoff has taken great pains to supplement his own knowledge of the art by consulting with three of the best professional glass-blowers of St. Petersburg. Consequently the book is characterized by giving the most minute details as to how to proceed in any given case. Undoubtedly it is very reliable and up to date. On the other hand, the volume is not well-balanced because pages 128 to 155 are devoted to the making of mercury-in-glass thermometers, while pages 155 to 195 deal with the calibration of such thermometers, a theme which pertains to laboratory manuals but not to a practical guide to glass-blowing. H. S. U.

II. GEOLOGY.

1. *West Virginia Geological Survey: Wirt, Roane, and Calhoun Counties;* by RAY V. HENNEN, Assistant Geologist. 1911. 573 pp., 3 maps, 15 plates, 6 figures.—In common with the previously issued West Virginia Reports, the description of Calhoun, Roane and Wirt counties is prepared in such a manner as to be directly useful to those interested in petroleum, gas and coal, and agriculture. The value of soil is particularly emphasized by the State Geologist and attention is called to the damage resulting from deforestation. A chapter on the Historical and Industrial Development of the area, and a meagre discussion of the Physiography is followed by a detailed study of the Geology, including chapters on General Geology, the Dunkard Series, the Monongahela Series, the Conemaugh Series. An unusually large list of carefully measured sections is given. An examination of the geologic structure shows the area to be located on the eastern flank of the Great Appalachian geosyncline, which in this area is modified by minor folds, embracing six anticlines and five synclines. The care with which structure contours have been worked out and recorded on the map is justified by the fact that structure is the primary control in the distribution of oil and gas,—the chief mineral wealth of this group of counties. The results of

strictly economic studies are recorded under the headings Petroleum and Natural Gas (pp. 276–467); Coal Resources (pp. 468–497); Clays, Road Materials and Stone (pp. 498–506). The chapter on Agriculture and Soils is the work of W. H. Latimer and F. N. Meeker of the Bureau of Soils. H. E. G.

2. *Geological Survey of New Jersey;* HENRY B. KÜMMEL, State Geologist. Bulletins 1-5, including Annual Report for 1910. 1911.—Beginning with the present report, the publications of the New Jersey Survey will be listed as Bulletins and issued in two forms,—separately and bound into an annual volume. The change will be welcomed by those who have occasion to use these valuable reports. Under the new arrangement the following bulletins have appeared:

Bulletin 1, Annual Administrative Report of the State Geologist for 1910. 43 pp.

Bulletin 2, Report on the Approximate Cost of a Canal between Bay Head and the Shrewsbury River, by H. B. Kümmel. 20 pp., map and profiles.

Bulletin 3, Flora of the Raritan Formation, by Edward W. Berry. 231 pp., 29 plates, 3 figures.

Bulletin 4, Description of the Fossil Fish Remains of the Cretaceous, Eocene and Miocene Formations of New Jersey, by Henry W. Fowler. 192 pp., 108 figures.

Bulletin 5, Mineral Industry of New Jersey for 1910, by Henry B. Kümmel and S. Percy Jones. 24 pp.

Announcement is made that an entirely new geologic map of the state is in preparation to replace the map of 1890, which is not only out of date, but has been out of print for many years. H. E. G.

3. *The State of the Ice in the Arctic Seas* (Isforholdene i de arktiske Have). 1911, pp. xxiii, 5 maps.—At the request of the Seventh International Geographical Congress, the Danish Meteorological Institute issues an annual bulletin on Arctic ice printed in Dutch and in English based on data from all available sources. The present report, prepared by Commander C. I. HANSEN, records by months the condition of the ice at various localities and a summary for each region. Separate maps for April, May, June, July and August are included. H. E. G.

4. *Wisconsin Geological and Natural History Survey;* E. A. BIRGE, Director; W. O. HOTCHKISS, State Geologist. Bulletin No. XXIII, Economic Series No. 14, 1911. Reconnoissance Soil Survey of Part of Northwestern Wisconsin, by SAMUEL WEIDMAN, assisted by E. B. HALL and F. S. MUSBACK. Pp. 102, map in pocket, 15 plates, 16 text figures.—The region covered by the Survey has an area of 6,705 square miles and includes the counties of Eau Claire, Chippewa, Rusk, Barren, Dunn, Pepín, Pierce, St. Croix, and Polk. In addition to a study of soils and of agricultural conditions, this report discusses the geology, geography, water supplies, climate, etc., and presents results in a manner very acceptable to those who wish a general knowledge

of the physical geography of this portion of the Prairie Plains Province.

5. *Annual Progress Report of the Geological Survey of West Australia for the year 1910.* Pp. 31; 2 maps, 2 figures. Perth, 1911.—The active staff of the Western Australia Survey includes the following officers in addition to A. Gibb Maitland, the Government Geologist: H. P. Woodward, Charles G. Gibson, H. W. B. Talbot, L. Glauert, and E. S. Simpson, the latter in charge of the Survey Laboratory. Four Bulletins were issued during the year, viz., Bulletin 36, Palæontological Contributions to the Geology of Western Australia, III (this Journal, xxxi, p. 239, 1911); Bulletin 38, The Irwin River Coalfield and the adjacent Districts from Arrino to Northampton (this Journal, xxxi, p. 239, 1911); Bulletin 39, Geological Observations in the Country between Wiluna, Hall's Creek and Tanami (this Journal, xxxi, 574); Bulletin 41, Geology and Ore Deposits of the West Pilbara Goldfield (in press).

The annual report for 1910 contains an interesting history of the Survey from its informal organization in 1847. Since 1887 the work has been carried on continually by a small but active group of geologists. The nature of the work undertaken may be judged from the list of publications which comprises 58 reports on gold deposits, 10 on copper and lead, 7 on tin, 3 on iron ores, 10 on coal and oil, 3 on phosphates, 12 on miscellaneous mineral deposits, 10 on general geologic subjects, 1 on petrography, 1 on paleontology, 23 on ground water. Besides preliminary reports on various phases of geologic work (chiefly economic) the Annual Progress Report for 1910 includes a discussion by Mr. Gibson of the "Principal Geological Features of the Kalgoorlie Goldfield," together with a geological map of this region, which has contributed more than half of the total production of gold in the state. H. E. G.

6. *The Uses of Peat.*—Bulletin 16 of the Bureau of Mines (pp. 214) contains an account by Charles A. Davis of the uses of peat for fuel and other purposes. The subject is one of importance, for thus far this country has made little progress in this direction, as compared with what has been done abroad. As fuel it has its highest value and is most efficient as a source of producer gas; but it is useful also, in place of wood, in brick manufacture, ceramic firing, and lime burning. This whole subject is discussed in much detail and many important facts brought out. Peat is also available in a variety of manufacturing purposes, as those calling for a fibrous vegetable product; the comparative abundance of wood has, however, prevented the development of this in the United States, as compared with Europe, where wood is much more scarce. Agriculturally peat lands may be cultivated with profit, if the right crops are chosen, and sufficient care is used to put the lands in the best condition by draining, decomposing, and fertilizing the peat.

III. Miscellaneous Scientific Intelligence.

1. *Carnegie Institution of Washington. Year Book. No. 10, 1911.* Robert S. Woodward, President. Pp. xvi, 296; 9 plates. Washington, January, 1912.—The publication of the tenth annual report of the Carnegie Institution is an event of much importance, and gains a special interest from the fact that during the past year an addition of $10,000,000 to the fund of the foundation has been made by Mr. Carnegie; the total endowment now reaches the princely figure of $22,000,000, yielding an annual income of $1,100,000. The past year has also been marked by the completion of the meridian astronomical work at the temporary observatory at San Luis, Argentina. The observations, carefully planned in advance by Professor Boss, were begun in April, 1909, and so expeditiously carried out that about a year since the observers returned to Dudley Observatory at Albany. Professor R. H. Tucker was the astronomer in charge of the work. It is also to be noted that the past year has seen the completion and equipment, at a cost of $25,000, of the 70-foot motor boat called the "Anton Dohrn"; it will be used for the department of Marine Biology, which has its center at Tortugas, Florida.

The sum allotted for the ten departments, to which the funds of the Institution are particularly devoted, amounted to very nearly $500,000, while about $100,000 more were appropriated for the minor grants, although not all expended. The total expenditures of the Institution since its beginning amount to about $5,500,000, of which $4,000,000 have been applied directly to research, more than $300,000 to publications, and $400,000 to administration. The Institution now owns two astronomical observatories, five laboratories and a non-magnetic ship, besides numerous buildings and pieces of real estate. Some 201 separate volumes have been published and a total of 90,730 volumes distributed.

The report of the President, from which these facts are taken, also gives a brief summary of the results accomplished by the several organized departments of research, ten in number, as well as of the investigations of the research associates. These subjects are further discussed in detail by the gentlemen in charge, who give a most interesting account of the work that has been prosecuted in their respective lines. It is only by a careful reading of these individual reports, which make up the bulk of the present volume, that an adequate idea can be obtained of the manifold results that are being accomplished by the Carnegie Institution. A special descriptive pamphlet of 34 pages with numerous illustrations has been issued commemorative of this tenth anniversary.

2. *Publications of the Carnegie Institution.*—Recent publications of the Carnegie Institution are noted in the following list (continued from vol. xxxii, p. 327):

No. 27. Bacteria in relation to Plant Diseases; by Erwin F. Smith. Volume II. History, general Considerations, Vascular Diseases. Pp. viii, 368; 20 plates, 148 figures.

No. 88, Part II. Dynamic Meteorology and Hydrography; by V. Bjerknes and different collaborators. Part II—Kinematics. Pp. vii, 175, 4to. 113 figures and 60 folio plates in separate cover.

No. 140. The Eusporangiatæ. The Comparative Morphology of the Ophioglossaceæ and Marattiaceæ; by Douglass H. Campbell. Pp. vi, 229; 13 plates, 192 figures.

No. 145. A Revision of the Cotylosauria of North America; by E. C. Case. Pp. iii, 122; 14 plates, 52 figures.

No. 146. Revision of the Amphibia and Pisces of the Permian of North America; by E. C. Case, with a description of Permian Insects by E. H. Sellards, and a discussion of the Fossil Fishes by Louis Hussakof. Pp. vii, 179, 4to; 32 plates.

No. 147. Determinations of Stellar Parallax; by Henry N. Russell, based upon Photographs taken at the Cambridge Observatory by Arthur R. Hinks and the writer, with Magnitudes and Spectra determined at the Harvard College Observatory under direction of Edward C. Pickering. Pp. iv, 142.

No. 155. A Comparative Study of Temperature Fluctuations in different Parts of the Human Body; by Francis G. Benedict and Edgar P. Slack. Pp. v, 73; 38 figures.

No. 156, Part II. Feeding Experiments with Isolated Food-Substances; by Thomas B. Osborne and Lafayette B. Mendel, with the coöperation of Edna L. Ferry. Pp. iii, 55–138; 2 plates, Tables XXXI–XXXVI, Charts XXII–CXXIX.

No. 157. High Temperature Gas Thermometry by Arthur L. Day and Robert B. Sosman, with An Investigation of the Metals by E. T. Allen. Pp. vi, 129; 18 figures.

No. 158. The Methods of Petrographic-Microscopic Research: Their Relative Accuracy and Range of Application; by Fred. Eugene Wright. Pp. 204; 11 plates, 118 figures.

No. 160. The Absorption Spectra of Solutions of comparatively Rare Salts, including those of Gadolinium, Dysprosium, and Samarium, etc.; by Harry C. Jones and W. W. Strong. Pp. viii, 112, with 67 plates.

No. 162. Ctenophores of the Atlantic Coast of North America; by Alfred G. Mayer. Pp. 58; 17 plates, 76 figures.

The Classics of International Law; edited by James Brown Scott. Iuris et Iudicii Fecialis, sive, Iuris inter Gentes, et Quaestionum de eodem Explicatio; by Richard Zouche, edited by T. E. Holland.

Vol. I. A Reproduction of the First Edition (1650), with Introduction, List of Errata and Table of Authors. Pp. xvi, 204.

Vol. II. A Translation of the Text; by J. L. Brierly. Pp. xvii, 186.

A pamphlet (pp. 90) under date of February 6, 1912 is devoted to a Price List, Classified descriptive Lists and Index of Authors.

3. *Elements of the Differential and Integral Calculus* (Revised Edition); by W. A. GRANVILLE. 8vo, pp. xv, 463 (Ginn & Co.).—Professor Granville's removal from the sphere of teaching to a college presidency will, it is to be feared, terminate his activity in the production of text-books in Mathematics. His Calculus is unequaled by any we know in the number and excellence of its working problems, on which in this subject preëminently the student's effective knowledge of the science must depend. The revised edition is enriched by considerable additions to the problems and by a portrait of Leibnitz. The changes in the text are unimportant. W. B.

4. *The Theory and Practice of Technical Writing;* by SAMUEL C. EARLE. Pp. vii, 301, with numerous figures. New York, 1911 (The Macmillan Company).—This work is of somewhat novel character, since it is planned to guide the engineer in his task of presenting his reports in a manner that shall be at once clear and effective. It has been assumed too much, hitherto, that technical writing would take care of itself, and hardly required the same care as discussions more general and literary in their character. The author discusses with much clearness the various principles of logical structure, and then the practical application of these to the cases in hand, which may be treated in different form, according to the audience for which they are prepared. The Appendix gives a series of useful illustrative examples.

5. *Publications of the Harvard College Observatory;* EDWARD C. PICKERING, Director.—Recent publications are noted in the following list (continued from vol. xxxii, p. 327):

ANNALS.—Vol. LXII, Part II. Ledger of Zone Observations made with the 8-inch Meridian Circle during the years 1888–1898; by ARTHUR SEARLE. Pp. 149–253.

Vol. LXXI, No. 2. Spectra and Photographic Magnitudes of Stars in Standard Regions; by WILLIAMINA P. FLEMING. Pp. 27–45.

CIRCULARS.—No. 167. Stars Having Peculiar Spectra. 31 New Variable Stars. EDWARD C. PICKERING. Pp. 3; 2 tables.

No. 169. Photometric Observations of Asteriods. Pp. 4; 1 figure.

6. *Publications of the Allegheny Observatory of the University of Pittsburgh.*—The following have recently been issued; Vol. II, No. 14. The Spectrum and Orbit of β Scorpii, by ZACCHEUS DANIEL and FRANK SCHLESINGER. Pp. 127–137.

A simple method for adjusting the Polar Axis of an Equatorial Telescope; by FRANK SCHLESINGER (Popular Astronomy, 1911).

MAJOR C. E. DUTTON.

Clarence Edward Dutton was born on May 15, 1841, in Wallingford, Connecticut, and died on January 4, 1912, at Englewood, New Jersey. He was graduated at Yale College in 1860 at the early age of 19 and entered the army in September, 1862 as 1st lieutenant and adjutant of the 21st Connecticut regiment. Six months later he was promoted captain. In 1864 he was transferred to the Ordnance Corps, reached the rank of Major May 1, 1890, and was retired at his own request with the same rank, Feb. 7, 1901.

Although he was in the military service from his majority to his death, the best years of his life were spent in geological work and it is for this that he will be remembered. As he informed Mr. J. S. Diller,* his interest was first attracted to paleontology, which he studied under the guidance of Hall and Whitfield, while he was stationed at the Watervliet arsenal. Later when at Washington he became acquainted with Henry, Baird and Powell and by the first was induced to consent to a detail for duty with the U. S. Geographical and Geological Survey of the Rocky Mountain Region, beginning May 15, 1875. In this position he devoted himself to the study of the Plateau regions of the far West and especially of the physical problems there presented. His results are recorded in three monographs of which the second forms Monograph II of the present U. S. Geological Survey and contains Mr. W. H. Holmes's marvellous illustrations of the Grand Cañon. The material for this volume and for his Geology of the High Plateaus of Utah had been gathered under the Powell Survey and thus belong to a period when "exploration" or "reconnaissance" represented more accurately than "survey" the standard aimed at. This was in the circumstances inevitable. At the close of the war of secession almost nothing was known of the geology of the far West and it was impossible even to plan a thorough survey until the general nature of the country had been ascertained. In addition to his own work he contributed lithological discussions to Mr. Gilbert's famous memoir on the Henry Mountains.

These early works of Dutton as well as his later publications are marked by clearness and simplicity of presentation. Very few American men of science have possessed to so marked a degree that sympathy with the reader which is the secret of arranging ideas in the order in which they will be most easily grasped, and that lucidity of statement unattainable without a copious vocabulary. Ease of expression, however, may be a dangerous gift and Dutton did not always reason soundly.

A writer thus gifted is not merely widely read and quoted but is given merit to which he makes no claim. Dutton frankly acknowledged the fact that Babbage and John Herschel before 1840 were independently led to the theory of isostasy. Dutton

* See Mr. Diller's excellent paper on Dutton, Bull. Seism. Soc. Amer., vol. i, No. 4, Dec. 1911.

of course only invented the name, but he is widely credited with being the first to announce the principle.

After the organization of the present Survey, Dutton was detailed to serve with it and, in a position nominally new, he continued to act with the associates of earlier years. In 1884 he examined Mount Taylor and the Zuñi Plateau, his memoir appearing the next year. This gave him an opportunity to modify, in the light of recent discoveries, some of his earlier views of the region.

After the completion of his Plateau studies Dutton's most important contribution to geology was his study of the Charleston Earthquake of 1886. In one respect he then had a unique opportunity. Clock time was standardized in the United States in 1883 and the Charleston earthquake was the first of consequence to occur in a region where clocks kept the same time or comparable time. Thus the observations of shock on that occasion could be coördinated as in no previous case and of this Dutton made full use. His method of ascertaining the depth of the hypocentrum is a somewhat rough one, but there is no reason to doubt that it gives the order of magnitude of the quantity sought in cases in which the shock may be regarded as emanating from a restricted space or area.

Dutton returned to military duty in September, 1890, but did not abandon his interest in geology. He took the occasion of furloughs to visit Mexican volcanoes as in earlier times he had visited Hawaii and thus collected much of the material for his last important work, "Earthquakes in the light of the new Seismology," 1904. This book shows Dutton at his best. It is excellent reading and contains much information, but it is far from being exhaustive and cannot be regarded as an adequate presentment of the subject at the time of its publication.

George F. Becker.

Professor Thomas Harrison Montgomery, Jr., of the Zoölogical department of the University of Pennsylvania, died on March 19 at the age of thirty-five years. Although a youug man he had already published a large number of papers on biological subjects and was the author of a work entitled "Analysis of racial descent in Animals."

Professor John Bernhardt Smith, of Rutgers College, and since 1894 State Entomologist of New Jersey, died on March 12 in the fifty-fourth year of his age. He was the originator of many of the modern methods of fighting the mosquito pest by drainage of swamps in which the insects breed.

Professor Ralph S. Tarr, of the department of Physical Geography at Cornell University, died suddenly at his home in Ithaca on March 21; he was forty-eight years old. A notice is deferred.

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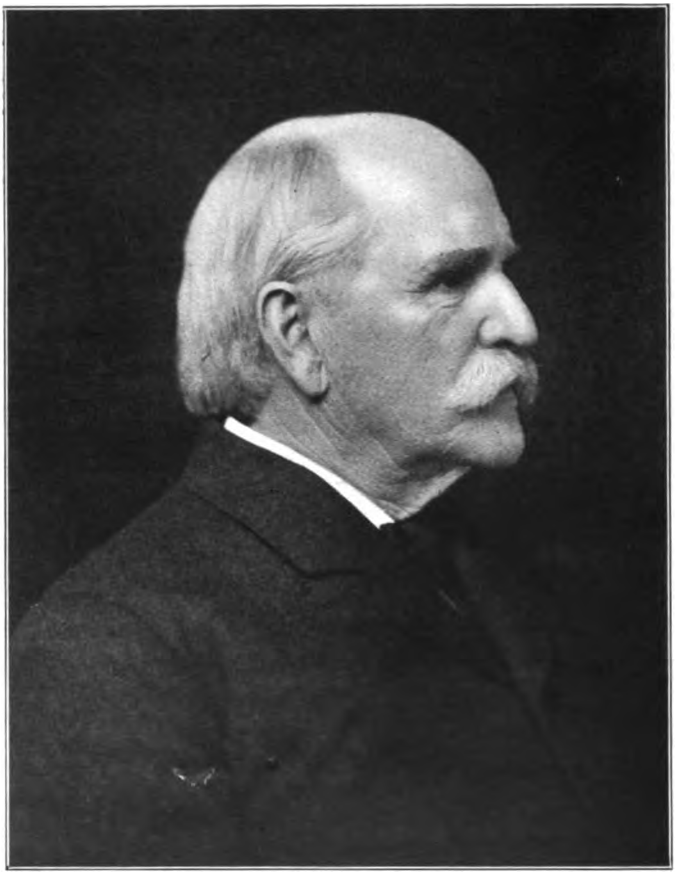

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

GEORGE JARVIS BRUSH.

PROFESSOR BRUSH, whose long life of active service for science and Yale University closed on February 6th, will always be remembered as a pioneer in the building up of scientific education in this country. His energy, his indomitable will, his courage in contending with obstacles, and his rare administrative ability were devoted, for nearly forty years, with intense singleheartedness to the School of science from which he obtained his degree in 1852. As the reward of his devotion and that of his colleagues, he had the satisfaction of seeing the School expand steadily from the smallest of beginnings until it was established as a vigorous and growing department of Yale University. He began his work when the value of science, and that of the scientific methods of the laboratory, were but meagerly appreciated in the country: when he resigned from active service in 1898, science had won a large place in every institution and schools of science were to be found at many centers of learning.

Professor Brush was also an able and trained worker in a special field of science, contributing largely to mineralogy through his own original work and acting as an inspiration to his students who carried on the research in his favorite subject when his energies were diverted into administrative lines.

GEORGE JARVIS BRUSH was born on December 15th, 1831. He was the seventh in line of descent from Thomas Brush who settled in Southold, Long Island, in 1653 and who is believed to have been the first of the name in America. The father of Mr. Brush was Jarvis Brush, and his mother, Sarah Keeler; the family home was in Brooklyn, N. Y., where the father was in active and successful business as a commission and importing merchant. In 1835, when still a young man, he retired from business, satisfied with the competency he had gained, and moved with his family to Danbury, Connecticut, where he resided for some six years until 1841, when he

returned to Brooklyn. The early education of George was received in private schools in these two places. When fifteen years old he was sent to a school at West Cornwall, Connecticut, kept by Mr. Theodore S. Gold, and it was here that his interest in science was first aroused. Mr. Gold was an admirable teacher for such a student, for he was enthusiastically devoted to mineralogy and other branches of natural history, and had a rare power in arousing the interest of his pupils in these subjects. Although young Brush was with Mr. Gold only six months, the effect upon his subsequent career was profound. The evidence of this was not shown, however, at once, for the traditions of the family led him to look forward to a business life. After leaving the West Cornwall school he took a position with a mercantile house in Maiden Lane, New York City, and remained there about two years; occasional mineral excursions were his only indulgence in science. But fate had a wider career in store for him. In consequence of a serious illness in 1848 he was compelled to give up the confining life of business, and it was decided that he should devote himself to farming. This decision led him to come to New Haven in October, 1848, to attend the lectures of Professors John P. Norton and Benjamin Silliman, Jr., in agricultural and practical chemistry, recently established in connection with Yale College. The College catalogue for 1848 includes his name as a member of the second class in the "School of Applied Chemistry." His work in New Haven was, however, interrupted when in October, 1850, he went to Louisville, Kentucky, as assistant to Professor Benjamin Silliman, Jr., instructor of chemistry and toxicology in the medical department of Louisville University, a position which he retained till the spring of 1852. During this period, in the spring and summer of 1851, he travelled extensively in Europe as one of the party of the elder Professor Benjamin Silliman. At the Yale commencement of 1852, after a special examination made necessary by the absence alluded to, he received the new degree of Ph. B. just established. It is most interesting that the man who was destined to build up this department of the institution into the strong and flourishing Sheffield Scientific School should have been a member of the first class to receive a degree. In this class of 1852, which began with fourteen members, seven were graduated, four of whom later became prominent in science, and one of these, Professor William H. Brewer, worked shoulder to shoulder with Brush in the work for the School for many years.

The college year of 1852–53 was spent as assistant in chemistry at the University of Virginia, and it was here that, associated with Professor J. Lawrence Smith, a series of studies were prosecuted on the "re-examination of American minerals"; three

papers with this title were published in volumes xv and xvi of this Journal. This work in mineral chemistry served to show both his ability in research, his grasp of scientific methods, and his interest in the subject. It also made him feel the necessity of further scientific study and training; and, after spending the summer of 1853 as assistant in charge of the department of mineralogy in the Crystal Palace at the International Exposition in New York, he sailed in the following November to Germany. The years 1853 to 1855 were spent in Germany, at first at Munich with Liebig, von Kobell, and Pettenkofer, and later at the mining school at Freiberg, Saxony. These years were rich in results, not only in the scientific training they gave, but also in the opportunities for close association with his professors and fellow students.

In 1855 Mr. Brush was elected professor of metallurgy at New Haven, in the Yale Scientific School that had been slowly developing ever since its beginning in 1846. To train himself for his future work he spent another year abroad, studying at the Royal School of Mines in London and also visiting the chief mines and smelting works of Great Britain and the continent. In January, 1857, he entered upon the duties of his professorship of metallurgy: later, in 1864, his chair was broadened so as to include mineralogy, and in 1871 it was finally limited to the latter subject, the one in which he was particularly interested. Of his work after the time when he became professor in the Scientific School, one who was later his colleague for many years wrote of him in 1881: *

"From this time on the history of Professor Brush has been the history of the special scientific department of Yale College, which, in 1860, owing to the liberal benefactions of Mr. Joseph E. Sheffield, received the name of the Sheffield Scientific School. He came to it while it was not only without reputation, but without appreciation or expectation. He came to it while it was poor beyond even that decent poverty which apparently belongs, in the nature of things, to institutions of learning—while it was in a state of mind so unorganized that as a whole it could hardly be said to have a being at all. It exhibited, indeed, a good deal of life in the College catalogue, but beyond that its vitality did not extend. There was vigor enough in certain of its departments, especially in that of civil engineering, under the charge of Professor William A. Norton; but in such cases it was a vigor due to the energy of the individual instructor, and therefore almost certain to disappear whenever he disappeared. To bring these scattered units into an organic whole, to build up a complete and consistent scheme of scientific education, which should have both definite and lofty aims, which should train men thoroughly in scientific methods, and which should continue to exist by its own inherent vitality after the men who established it should have passed

* Popular Science Monthly, vol. xx, pp. 119, 120, Nov. 1881.

away—all this became by degrees a main work of Professor Brush's life. His energy, his judgment, his executive capacity, and his devotion soon gave him the leading direction in the affairs of the institution. He was for a long period its secretary; he has always been its treasurer; and when, in 1872, a more formal organization of its faculty was felt to be desirable, he was elected as its presiding officer, a position which he still retains. Others have done their part toward developing various departments of the School, but its growth, as a whole, the position which it has acquired among scientific institutions, whatever that position may be, has been due to him very much more than to any other one man connected with it. . . ."

In 1872, as above stated, Professor Brush was made director of the Sheffield Scientific School, to which he had already devoted fifteen years of his life. This position he held until 1898, when he resigned his active duties, both professorial and administrative. His time and energies of necessity were, from 1872 on, more and more absorbed by the labor of planning for the School as a whole and caring for its many interests. In 1873, Dr. George W. Hawes was appointed assistant in mineralogy, and much of the active work of teaching devolved upon him; thus in the later seventies, Professor Brush had practically resigned his laboratory instruction and finally, in 1884, he was compelled to give up his lectures also. Dr. Hawes remained in charge of the department until 1879, during which time the classes in laboratory work were transferred to the Peabody Museum after its completion in 1876. In 1879, Dr. Hawes was called to Washington and Dr. S. L. Penfield took his place as instructor in mineralogy; later the latter was made assistant professor (1888), and finally professor of mineralogy (1893); in his able hands Professor Brush felt that his favorite subject was fully cared for, as was well proved by the work that was published from the Sheffield laboratory of mineralogy. It may well be imagined with what deep sorrow the elder Professor saw each of his assistants and helpers cut down in their prime, Hawes in 1882 and Penfield in 1906.

In 1898, as has been stated, Brush resigned his active responsibilities as professor and director. The remaining years of his life were for the most part spent in New Haven in close touch with the same interests to which he had devoted his life. He continued as secretary and treasurer of the Sheffield Trustees until 1900, when he retired as secretary and was elected President of the Board. He gave up the treasurership in 1904, but retained the presidency until the end, presiding at the annual meeting in November, 1911.

During the period that has been alluded to, Brush took the liveliest interest in all that pertained to mineralogy, the instruction, the active research, and the increase of his private collec-

tion, although he himself, as he sometimes a little pathetically expressed it, was "doomed to turn the crank of the machine." The various duties of the director of the rapidly growing School, financial and administrative, were, however, fully to his taste, and it can hardly be regretted that his time and strength were given so fully to them. His health, on the whole, was not seriously impaired as years increased, until the spring of 1911, when a trouble with the heart developed which from that time increasingly limited his physical activity. The decline was slow and for the most part, until near the end, without suffering, and on February 6th he passed gently away. The great kindliness of his strong nature was never shown more clearly than in the closing months of his life. In 1864 he was married to Harriet Silliman Trumbull, who died in 1910; three daughters survive him.

The interest taken in minerals by Mr. Brush when a boy of fifteen, was rapidly developed during his student years under the stimulating influences at Munich and Freiberg. This interest continued unchanged through his life, though, as has been stated, the pressure of administrative work finally robbed him of the opportunity for active study. He developed early a remarkably keen eye for recognizing mineral species, even those which were a puzzle to an ordinary mineralogist. When a schoolboy with Mr. Gold he began to collect minerals, and as years went on and his ability to obtain specimens by purchase or exchange increased, he accumulated a large and very valuable collection. This collection was especially notable for its completeness for the purposes of scientific study and the type specimens which it contained; the history of each specimen was also recorded with the utmost care. His active work as a collector, aided by that of his associates, continued till 1904, when he formally presented his collection, then numbering about 15,000 specimens, to the Sheffield Scientific School, adding to this gift a fund of $10,000 for its maintenance and increase. This collection was housed in the old building of the Sheffield School until its removal to his room in the Peabody Museum in 1876. Here it remained until 1904, when it was placed in a room specially prepared for it in Kirtland Hall. He took the greatest satisfaction in having it cared for, arranged, and catalogued; and one of the keenest pleasures of his later years consisted in going over the collection and aiding in the final work upon it.

A mineralogist with so keen an eye and interest in his subject must of necessity have been both a teacher and investigator. In the former direction the influence of Professor Brush was widely felt, particularly during the decade beginning with 1864. Many students were inspired by his enthusiasm and carried the knowledge and skill acquired from him to other

centers of learning. The work of Professor Brush in the original study of minerals began in 1849, when he was only eighteen years old. From then for twenty-five years he was active, and a series of about thirty papers gives a record of the results attained. In 1878 and later, he took time from his absorbing administrative labors, and, in conjunction with a younger colleague, published a series of papers on the newly discovered locality at Branchville, Connecticut.

In 1874 his "Manual of Determinative Mineralogy" was brought out; this contained a clear summary of blowpipe methods and principles, and also a series of determinative tables adapted from the German tables of von Kobell. In the preparation of this work, especially the latter part, Dr. Hawes took a prominent part. A revised edition was issued in 1878, and later the work was entirely rewritten on an expanded scale by Professor Penfield. The most important editions of the book as thus revised were those of 1896 and 1898. Professor Brush also made important contributions to the System of Mineralogy of Professor James D. Dana. Of the ten supplements to the fourth edition of 1854, he prepared the eighth, ninth and tenth. In the preparation of the fifth edition of 1868, he took an important part: the statements of the blowpipe characters of the different species were written by him, and in most cases the facts given were based upon his own independent experiments. His close knowledge of mineralogy also enabled him to aid the author at many points in the prosecution of his task. The first appendix to the fifth edition, issued in 1872, was prepared by Professor Brush. Another contribution to the science to which he was devoted was the presidential address before the American Association for the Advancement of Science at Montreal in 1882; this was a thorough and valuable summary of the early history of American Mineralogy. Professor Brush became an associate editor of this Journal in 1863 and retained that position until 1879. The pages of the Journal contain about all of his papers on mineralogical subjects.

It has been shown that the influence of his early life tended to turn Mr. Brush into an active business career. Fortunately for the world this was not to be his life's work, but to one familiar with him and what he accomplished, the influence of this early training is clearly shown. He was distinctly a man of affairs, of quick, sure judgment, firmness of resolution, and great energy. The successive steps by which the Sheffield Scientific School grew under his guidance from 1857 on show at every stage his ability and his strong hand. This is not the place to go into this subject in detail, but the success of this, the most important work of his life, can hardly be overesti-

mated. The School at the beginning had almost no funds, but it early attracted the interest of Mr. Joseph E. Sheffield and this interest was wisely and tactfully guided and stimulated by Mr. Brush. As the result of this, the School received from Mr. Sheffield a considerable endowment and in 1861 was formally called the Sheffield Scientific School. The endowment was still further increased later, especially by the provisions of the will of Mr. Sheffield, who died in 1882. It would be difficult, without detailed historical discussion, to give any adequate idea of the complexity and difficulty of the problems of the growing School and of the skill and wisdom with which they were met and solved by Mr. Brush. One particular matter may be mentioned here. The School, in 1863, became the land grant College of Connecticut under the land grant act of the Federal Government. The sale of the land yielded an income which was most important to the School at a critical time in its growth. Later, in 1892, this fund was transferred by the State to the Storrs Agricultural College, but in the contest over the subject the interests of the School were so ably handled by Mr. Brush that in the settlement it received outright a sum of $150,000, thus putting it in a better position than that which it had before occupied.

The financial skill shown in the management of the interests of the School was also used for the benefit of the funds of the Peabody Museum, of which Mr. Brush was one of the original trustees appointed in the deed of gift of Mr. George Peabody in 1866. It was largely through his able management that the original $150,000 grew so steadily and surely that the $100,000 set apart at the beginning amounted to the $176,000 needed to pay for the building completed ten years later. Mr. Brush sometimes alluded with satisfaction to the fact that he had the foresight to exchange the five per cent Massachusetts State bonds of the original Peabody gift for the seven-thirties of the civil war loan, thus producing a rapid increase in the available funds. It is also interesting to note that for many years he was a director in the Jackson Iron Company of the Lake Superior district. He was, further, a director in the New York, New Haven, and Hartford Railroad from 1893 until his death, attending all the meetings with great regularity.

Professor Brush was elected a member of the National Academy of Sciences in 1868 and received the degree of Doctor of Laws from Harvard University in 1886. He presided as president of the American Association for the Advancement of Science at Cincinnati in 1881, and delivered the presidential address at Montreal the following year. He was an honorary member of the Mineralogical Society of England, a foreign member of the Geological Society of London,

of the Geological Society of Edinburgh, of the Royal Bavarian Academy of Sciences of Munich, and various other learned societies, both at home and abroad.

The portrait accompanying this sketch has been reproduced from a photograph taken about 1897. E. S. D.

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ART. XXXIV.—*The Life of the Connecticut Trias;* by RICHARD SWANN LULL.*

[Contribution from the Paleontological Laboratory, Peabody Museum, Yale University, New Haven, Conn., U. S. A.]

ONE of the most interesting chapters in the earth's past history is that of the time when there were laid down the Triassic strata of the famed Connecticut valley, interesting in the profusion of its indicated life, and fascinating in the baffling obscurity which shrouds most of its former denizens, the only records of whose existence are "footprints on the sands of time."

It is not surprising, therefore, that geologists should have turned to the collecting and deciphering of such records with zeal; nor is it to be marveled at that, after the exhaustive researches of the late President Hitchcock, workers should have turned to more productive fields, leaving the footprints aside as relics of little moment compared with the wonderful discoveries of the great unknown West.

Except for small summary papers by Professor Charles H. Hitchcock containing descriptions of some new species, and occasional papers by other authors, nothing was done from the time of the publication of Edward Hitchcock's notable "Ichnology of New England" in 1858, and the Supplement to it in 1865, until 1904, when a new study of the tracks in the light of recent paleontology was published by the present author.

Skeletal remains which were brought to light from time to time were described mainly by Professor Marsh in this Journal, and by E. Hitchcock, Jr. (1865) and by Cope (1869); and later summarized by Marsh in his "Dinosaurs of North America" (1896).

A final, more exhaustive study of the skeletal remains was made by Professor Friedrich von Huene in his "Dinosaurier

* Extracted from a monograph on "Triassic Life of the Connecticut Valley," to be published as a Bulletin of the Connecticut Geological and Natural History Survey. By permission of the Director, Professor William North Rice.

der Aussereuropæischen Trias." No serious attempt, however, has been made to reconstruct the physical conditions of the Trias and to repeople the Connecticut lands of that time with their living, breathing, strenuous inhabitants. The purpose of this essay, therefore, is to reconstruct the environment, both physiographic and climatic, to clothe it with its proper vegetative life, and to discuss as fully as may be the animate nature of that distant day.

One of the most remarkable features of the fossil remains of the Connecticut valley is the dearth of actual bones and the marvellous abundance of footprints—conditions exactly the reverse of those found in other fossil fields, for, outside the Triassic of New England and New Jersey, footprints are rarely met with, whereas the bones in some localities are nearly as numerous as in the Valley of Dry Bones, the vision of which was vouchsafed to Ezekiel. Somewhat similar conditions to those in the Connecticut valley seem to prevail in the Southwest and elsewhere, but in no other known locality is the profusion of footprints so great. In spite of this the discovery of bones preceded a scientific appreciation of the tracks by nearly a score of years, though doubtless the latter were often seen by observers like Pliny Moody in 1802, who failed to realize their great significance. The reference of one to the footprint of "Noah's raven" is probably only one of the many similar interpretations in the folk-lore of the Connecticut valley.

The profusion of species of animals represented by the tracks, which of course included the creatures the skeletons of which are known, is, so far as my present knowledge goes, as great if not greater than that of any other known vertebrate fauna of prehistoric times, and emphasizes once more the usual incompleteness of our geologic record and the countless multitudes of creatures which peopled our globe in the more remote ages.

The Connecticut Valley.

The tracks of the Newark system, which include the fossils under consideration, occupy a number of areas along the eastern coast of North America, of which the best known are that of the far-famed Connecticut valley, and the adjacent one stretching from New York through New Jersey, Pennsylvania, and Maryland into Virginia.

The Connecticut valley area, extending as it does across the states of Massachusetts and Connecticut, follows in general the depression now occupied by the Connecticut river, except in its lower course where the river forsakes the ancient valley at Middletown and cuts its way through the Eastern Highlands, reaching the Sound far to the eastward. The length of the

Triassic trough is about 110 miles, from the village of Northfield, Massachusetts, on the north, to New Haven bay on the south. Its width varies, but averages some 18 miles, the total area being not far from 2000 square miles.

This Triassic depression is bounded on either side by elevations of the more ancient crystalline rock, none younger than the Paleozoic, the weathering of which constituted the source of the Triassic sediments. The age of the latter, which has been referred to the Newark system, is usually correlated with the Rhætic of the Old World, though Eastman in his recent paper on the Triassic fishes of Connecticut (Bulletin 18, Conn. Geol. & Nat. Hist. Survey, p. 32), in speaking of the fish fauna, says: "The Triassic fish fauna of eastern North America is of a more or less manifold nature, and corresponds in a general way to the interval between the uppermost Muschelkalk and the basal division of the Keuper in the Mediterranean region." The English footprints found in the Lower Keuper Storeton quarry near Liverpool, however, do not resemble those of the Connecticut valley in a single instance, though a three-toed dinosaurian track described by Sollas as *Brontozoum thompsoni* which was found at Newton Nottage, Glamorganshire, and referred to the Lower Keuper (Magnesian Conglomerate), shows affinities with those in the Connecticut fauna.

According to the usage of the United States Geological Survey, the non-committal name of Jura-Trias has often been applied to the strata in North America, and as I shall show, the very distinctive dinosaurian fossils are confined to the upper portion of the Newark system both in the Connecticut valley and in New Jersey, while in the lower beds creatures of very different rank predominated.

In a region of the classic interest which envelops the Connecticut valley, embracing as it does some of our most venerable seats of learning, and cradling some of America's greatest geologists, it is not surprising that the discussion as to the origin of the Newark rocks should have been animated. The theories of the method of deposition vary all the way from submarine, through estuarine to continental, and involve a considerable range of climatic conditions as well.

Emerson, in the Holyoke Folio (1898), p. 8, discussed the origin of the Newark deposits in the Connecticut valley as follows:

"The events of the Paleozoic age, constituting a prolonged history of geographic changes, had come to a close, and a land not greatly unlike the present in general configuration had been established, when a new sedimentary record was begun in a bay occupying the position of the Connecticut Valley in

Connecticut and Massachusetts. The shores of the bay were the west scarp of the Worcester County plateau on the east and the east scarp of the Green Mountain plateau on the west, and extending from near Brattleboro, Vermont, to New Haven, Connecticut. The sea waters rose to a considerable height above the present level of the bordering plateaus and spread sediments brought in from these elevated regions on either side of the bay. The shoreward sediments on the east are represented by the Mount Toby conglomerates, and the Sugarloaf arkose is the synchronous deposit formed along the western shore. The Longmeadow sandstone was deposited in the shallower and quieter off-shore area, and in the central zone of the latter area, where the basin was widest, the still finer Chicopee shale was laid down. All these deposits are partly contemporaneous sediments, differing as the strength of the current and the character of the shore rocks affected them. Strong tides, like those of the Bay of Fundy, seem to have swept up the west side of the bay, carrying the material of the granitic shore rocks far north, to rest against a shore made of dark schists, and the return currents ran along the east shore, carrying the eastern shorewash south, while quieter waters and shifting currents spread the sediments in the central area.

"The accumulation of sediments was interrupted by an eruption of lava through a fissure in the earth's crust, which opened along the bottom of the basin. The lava flowed east and west along the bay, as tar oozes and spreads from a crack, and solidified in a sheet which may have been 2 or 3 miles wide and about 400 feet thick in its central part. This is the main sheet or Holyoke diabase. This sheet was soon covered with sand layers, but its thickness was such that it shallowed the waters to near tide level, and thus occasioned extensive mud flats. This was an area suitable for the formation and preservation of unique records of the life of the time. The curiously shaped and often huge reptiles of that age wandered over the mud exposed at low tide, and their footprints, being covered by the deposit of the next flood tide, constitute the so-called 'bird tracks' which have been found in such great numbers and perfection.

"The sands had reached a considerable thickness over the first trap bed when a second outflow of the trap followed, represented by the posterior bed or Hampden diabase. Immediately after the outflow of this sheet an explosive eruption took place, and blocks of diabase and pulverized lava were spread by the waters over a broad area, forming the Granby tuff bed. A third period of volcanic activity followed, during which a line of small volcanoes broke out along the old fissure beneath the bay. The area was next the scene of dislocations or faults, by

which the mass of sediment and volcanic rocks was divided into great blocks, often extending north and south. The blocks slipped one past another along nearly vertical planes. In these dislocations the strata were generally tilted eastward. . . . In these movements, associated perhaps with general uplift of the area, the bay became land and the rocks were exposed to erosion."

A view of the deposition of the Newark rocks more in keeping with the organic phenomena is that set forth by Davis in 1898 (pp. 32, 33) as follows:

"The pre-Triassic peneplain might have been warped so as to alter the action of the quiescent old rivers that had before flowed across it, yet not to drown or to pond them. Such a change would set the streams to eroding in their steepened courses, and to depositing where their load increased above their ability of transportation. As with marine or lacustrine deposits, the thickness of the strata thus produced would depend on the duration of the opportunity for their deposition. A progressive warping, always raising the eroded districts and depressing the area of deposition, would in any of these cases afford the condition for accumulating strata of great total thickness. The heavy accumulations of river-borne waste on the broad plains of California, of the Po, or of the Indo-Gangetic depression, all agree in testifying that rivers may form extensive stratified deposits, and that the deposits may be fine as well as coarse. They are characteristically cross bedded and variable, and they may frequently contain rain-pitted or sun-cracked layers. . . .

"In contrast to marine deposits, Penck has suggested the name 'continental' for deposits formed on land areas, whether in lakes, by rivers, by winds, under the creeping action of waste slopes, or under all these conditions combined. This term seems more applicable than any other to the Triassic deposits of Connecticut. It withdraws them from necessary association with a marine origin, for which there is no sufficient evidence, and at the same time it avoids what is to-day an impossible task—that of assigning a particular origin to one or another member of the formation. A continental origin of the formation would accord with Dana's conclusion that the Triassic beds 'are either fresh-water or brackish-water deposits.' There may possibly be included an occasional marine deposit along the axis of the depressed trough, for at one time or another a faster movement of depression than usual may have outstripped deposition and thus caused submergence; but, in the absence of marine fossils, the burden of proof must lie on those who directly maintain the occurrence of marine deposits."

In general geologists now regard the theory of the continental deposition of the Connecticut valley sediments as definitely proven.

The Physical Environment.

The weight of evidence seems to show that the physical environment within which the animals of the Triassic lived consisted of several broad depressions along what is now the northern Atlantic coast. It is, nevertheless, inconceivable that creatures of such ample locomotive powers as the majority of the Connecticut valley remains would imply were limited to the actual troughs, but they must have roamed far and wide across the uplands as well, though naturally their records of wanderings would only be made where sedimentation was in progress.

The climatic conditions of Triassic times may be judged by three criteria: the character of the sediment itself, the physical phenomena impressed upon the strata, and the evidence of the organic life.

Barrell (1908, p. 183), who has made extensive studies upon the relations between climate and sedimentation, comes to the conclusion that the "dominant red color of the whole of the Triassic formation, considered in connection with its feldspathic sandstones, indicative of the kind of erosion, mud-cracked shales, disseminated gypsum, and calcite, indicative of conditions of sedimentation, point . . . to a subarid climate," and furthermore that "the Triassic conglomerates . . . are associated with many features of climatic significance . . . which independently indicate a semiarid climate with hot summers and possibly cold winters" (p. 259).

Fenner (1908, p. 305), in describing the shales of the New Jersey Newark areas, summarized the physical phenomena thus:

"They are finely comminuted siliceous material, strongly impregnated with oxide of iron. Their laminations may be paper-like in thinness, but are generally coarser. On exposure to the weather they break up into a multitude of crumbly fragments. Mica scales are very plentiful. The surfaces of the laminæ frequently show a multitude of irregular markings —grooves, pits, curved lines, lumps, smooth patches of irregular shape, etc., not all of which can be deciphered with any certainty. Many, however, can be identified. Mud-cracks, rain-pits, and worm-grooves are frequent. Rill-marks are sometimes found. At times films of impalpable sediment are found in the depressions in the lumpy surfaces of certain sandstone layers, which, in their delicate markings, suggest irresistibly the frothy scum left in hollows after a rain."

One very characteristic physical phenomenon impressed upon the sandstones and shales of the Connecticut valley is that of mud-cracking as the fresh deposits dried under the ardent heat of the Triassic sun. These cracks are often found associated with the fossil footprints, and in many instances, notably from the Portland, Connecticut, sandstone quarries, they lie in the axes of the digital impressions, often radiating from the tips of the toes, thus showing conclusively that the drying was subsequent to the passage of the animal, the cracks following the already weakened lines of least resistance.

Yet another very characteristic Connecticut valley phenomenon is that to which the elder Hitchcock gave the poetic name of "Nature's Hieroglyphics." As he says, the most remarkable locality is at the Portland quarries, "where sometimes the surface looks like mosaic, or rather like a pavement of polygonal masses, with mortar between the pieces." Barrell describes this as "mud-cracks filled with æolian sands." He says (pp. 279–80):—

"Silt and sand will be blown over and fill up the cracks developed by the drying of argillaceous water-laid deposits. Consequently, the sand is filled in under the raised rims of the polygonal discs and becomes continuous with the mantle of sand above. In this way the concavity upward of the individual plates is preserved and the mud-cracks are not obliterated, even in a silty clay which would crack and crumble immediately upon being rewet by the advancing waters of the following inundation. Experiments by the writer [Barrell] go to show that the upturned edges of the clay plates would not usually hold their form while the broad sweep of sand-laden waters should deposit clean sand both under the edges and over the plates. The concavity of the plates thus testifies to æolian burial and such may be distinguished from mud-cracked flats buried by fluvial action."

Other phenomena indicative of climatic conditions are the impressions of frequent hard showers, such as are often observed in semi-arid regions, and pieces of recent sun-cracked mud deeply pitted with rain impressions secured by Professor Marsh on the Laramie plains in 1868 might well be of Triassic origin.

Still other phenomena, namely the impressions found in Portland and attributed to a fucoid to which was given the name of *Dendrophycus triassicus* by Newberry (1888, p. 82), have been seen in actual formation upon the clay banks of streams, and are nothing less than the wonderfully wrought-out series of branching rill marks made by tiny streams of trickling water.

The animals of the Connecticut Trias, in so far as they

throw light upon past climatic conditions, include the remains of at least two species of shells, both belonging to the fresh-water Unionidæ, which preclude the possibility of saline tidal waters, at least in the neighborhood of Wilbraham, Massachusetts, a locality which, unfortunately for the estuarine theory of origin, is far to the south of places where the sediment would seem to demand the strongest tides. On the other hand, the presence of shells implies more or less permanent waters, either in slow moving or impounded condition. The one insect reported from the valley is found in great abundance at Turners Falls, Massachusetts, and has been described as the aquatic larva of a neuropterous insect, hence again implying the presence of waters of some duration. If the period of larval life was equivalent to that of the ephemerids of to-day, the water must have continued not one season but three; this may, however, have been an annual insect the larval life of which would require but a transitory stream. The invertebrate trails show no characters which would debar them from such a climatic environment as Barrell has assumed for the Connecticut Triassic.

Fishes are, with the exception of one crossopterygian, all ganoids. And, while confined stratigraphically to two or three black shale bands, their geographical range is from Turners Falls to New Haven. They are, however, all of fresh-water affinities, and may well represent the recurrence of climatic cycles of greater than average humidity and consequent expansion of the aquatic habitat, or a disturbance of the drainage, due to volcanic damming or deformation, the climatic conditions remaining constant.

Over the terrestrial vertebrates, aside from a few of the forms unquestionably dinosaurian, so deep a shadow of obscurity rests that safe conclusions may hardly be drawn. There is no reason to suppose that all are reptilian; and, if the Amphibia of that day were of similar constitution to the present-day descendants, to whom a one per cent solution of salt is fatal, the proof of their presence would preclude the possibility of marine waters, and add their evidence in favor of continental deposition to that of the lower forms. There are, however, stegocephalians known from brackish water deposits.

On the Laramie plains in 1899, when conditions were dry even for a semi-arid climate, I found in the dust of the ground within the tent a large and lively salamander of brilliant coloring whose advent and departure were alike mysterious. Van Dyke in his description of the desert remarks that all desert trails run in straight lines, showing the animal to be not prowling but intent in getting across to the mountain. The same is true of the fossil trails of the Connecticut valley; and from the

compact type of foot, long stride, sometimes suddenly lengthening marvellously, and the narrow trackway of many species, it can easily be seen that the character imposed by the desert of speed and great travelling powers was here at a high premium. As I have shown elsewhere (1910, p. 37), a climate of semi-aridity, compelling cursorial adaptation as a means of getting food but more especially water, may well have been an impelling cause in dinosaurian evolution. Bipedality among lizards of to-day is, so far as I am aware, confined to denizens of semi-desert environment, certain instances being the large frilled lizard, *Chlamydosaurus* (Sayville Kent), of Australia, and several lacertilian species of our own Southwest.

That water was rare and at a premium when the rains did come is evidenced by the frequency of the association of rain-prints with dinosaurian tracks and the above-mentioned mud-cracks which *followed* the passage of the animal. Again, the depth of the impression of the tracks of two species of animals upon the same strata is sometimes entirely out of proportion to the apparent difference in the makers' size, for the presumption is that then as now the supporting area of an animal's feet must have borne a certain ratio to the weight in accordance with the type of environment to which the creature was adapted. The inference is, therefore, that the passage of the two animals was on their way to or from a water hole during a period of desiccation, and that the deeper impression was made some time before the shallower one and nearer the time of the preceding rains.

The Vegetal Environment.

Chamberlin and Salisbury (Vol. iii, pp. 38–40) speak thus of the plant life of the Triassic:

"The record of the vegetation is very imperfect. The vegetation was probably scanty in reality, for . . . arid tracts imply conditions inhospitable to plant life. An environment that could give rise so generally to coarse red sandstones and conglomerates—even limestone conglomerates—could not well be congenial to luxuriant vegetation.

"The Triassic was distinctly an age of gymnosperms the world over; the supremacy of the pteridophytes had ceased, though ferns, true to their persistent nature, still held an important place, and the equisetales were a more vital factor than now. . . . conifers of the types that had come in during the Permian, and kindred new ones, were prominent, while the cycadean group was still in a stage of deployment and occupied the central place of interest. . . . The Triassic conifers bore the scrawny aspect of the walchias and voltzias of the Permian. . . . It does not appear from the record that

any of these gymnosperms were especially large, but on the contrary rather dwarfish, the conifers bearing the aspects now found on sandy barrens and arid tracts. The calamites had given place to true equiseta, which were represented by forms that were gigantic in comparison with modern types. . . .

"In the closing stages of the period, the Rhætic epoch and its equivalents, there seems to have been much amelioration of the previous hostile conditions and a much ampler development of the flora. The larger part of the known American fossils belong to this stage. In favored portions of the Newark series from Connecticut to North Carolina, plant remains occur, and in the coal-beds of the latter state and of Virginia, the flora is more amply represented."

The Fauna.

In both vertebrate and invertebrate relics the proportion of known fossils to footprints is much the same, the former being of such extreme rarity as to warrant special mention of practically every find.

Invertebrates.

Of the actual fossils the species represented are but four,—two known species of molluscs, a small phyllopod crustacean, *Estheria* sp., and a single insect species of which fortunately there are numerous examples, all, however, from three or four localities in the neighborhood of Turners Falls, Mass., and near Middletown, Conn., though whether the latter locality yields the same form as that at Turners Falls is unknown.

A brief summary of the invertebrate species follows:

Of the phylum Arthropoda the Class Hexapoda is represented by the one known species *Mormolucoides articulatus* Hitchcock. This creature was first described by Hitchcock in 1858 as a crustacean and its true relationships were discovered by J. D. Dana, to whom Hitchcock sent specimens for examination. Dana, in a postscript to his letter reporting on the insect, says: "The larve was probably the larve of a neuropterous insect, which often has false legs along the abdomen; but, if so, it is surprising that there are no legs to the corselet, neuropterous larves having three pairs." This insect was afterwards studied by Scudder, who published an elaborate monograph amplifying the previous descriptions. It remained, however, for the present writer to have the good fortune to find upon a single individual among many impressed upon the shale, well-preserved remains of the antennæ and limbs which served still further to verify the taxonomic conclusions of Dana. These are described in detail in the memoir from which this extract is made. The further placing of this insect

in the classificatory scheme brings it into the order Neuroptera, family Sialidæ.

A second arthropod has just been announced (Jan. 1912) by Miss Mignon Talbot, professor of geology in Mount Holyoke College, and represents in all probability a new species of the phyllopod genus *Estheria*, heretofore reported from the New Jersey–Pennsylvania area but not from the Connecticut valley. The locality is West Holyoke, Massachusetts, which would place it geologically in the "Lower Series of granitic, coarse sandstones," exactly what one would be led to expect from the distribution of the genus in the New Jersey–Pennsylvania area.

Mollusca have been reported several times from the Connecticut valley, but the only authentic find seems to be that recorded by Emerson (1900, p. 58). This slab, which has been sent to me for study, is from near Wilbraham, Massachusetts, and contains at least 14 imperfect impressions representing at least 2 species of undoubted *Unio*, the type of Emerson's species being similar to *U. alatus*. It should hereafter be known as *Unio wilbrahamensis*. The second species is quite distinct from the first but is too imperfect to characterize. It is also unquestionably *Unio*, and may hereafter be known as *U. emersoni* in honor of Professor Emerson. *Anoplophora*, the genus to which Emerson referred the first species, Schuchert says is probably always marine, and the shells in question are doubtless in fresh-water deposits. The slab, which is a portion of an ice-transported bowlder, the parent ledge of which is probably unknown and therefore not necessarily as far south in the valley as Wilbraham, gives evidence of having been deposited in permanent waters, a habitat in keeping with that of present-day Unios. Wilbraham being toward the eastern side of the valley, is, therefore, near the summit of the Newark series stratigraphically.

Invertebrate Trails.

A summary of the invertebrate trails given by Professor C. H. Hitchcock in 1889 is as follows:

Hexapod Arthropoda, 8 genera and 24 species.

Inferior Arthropoda, including larval forms and worms, 10 genera, 16 species.

Mollusca, 4 genera and 6 species.

Incertæ sedis, 5 genera, 6 species.

This places the total number of invertebrate and questionable trails at 52. In view of the number of undoubted vertebrate species known from the Newark system and the teeming number of living invertebrates, especially arthropods, compared with vertebrates, even under adverse climatic conditions, this

number does not seem excessive. In fact, I imagine it may fall far short of the number of continental invertebrates of Newark time. My own grouping modified from that of Hitchcock (1889) is as follows:

Phylum Arthropoda

Class Insecta

Genera *Acanthichnus* with 9 species; *Bifurculapes* with 5 species; *Lithographus* with 3 species; *Copeza* with one species; *Hexapodichnus* with 2 species; *Conopsoides* with 2 species; *Harpepus* with one species; *Sagittarius* with one species.

Class Incertæ sedis

Genera *Lunula*, one species; *Pterichnus*, 2 species; *Hampes*, one species; *Sphærapus*, 2 species; *Grammepus*, 2 species; *Stratipes*, one species; *Saltator*, 2 species.

Phylum Vermes

The old term Vermes is used as being more non-committal than Annelida, as one cannot be sure that in every case the following track-makers were oligochete annelids, though doubtless some were.

Genera *Herpystezoum* with 4 species; *Halysichnus*, 2 species; *Cunicularius*, one species; *Cochlea*, one species; *Cochlichnus*, one species.

Phylum Mollusca ?

Under this head are placed some peculiar multiple trails, the duplication of which seems to debar them from the worms.

Genera *Bisulcus*, one species; *Trisulcus*, one species.

Genera of doubtful origin and character.

Genera *Harpagopus*, one species; *Grammichnus*, one species; *Climacodichnus*, one species; *Ænigmichnus*, one species.

The Aquatic Vertebrates.

Among the vertebrate fossils found in the Newark rocks of the Connecticut valley, two classes, fishes and reptiles, are represented by actual osseous remains; the latter surely, and probably the Amphibia, are recorded by their footprints. Whether or not the two higher classes, the birds and mammals, are represented is not yet proven, though mammalian remains are known from the Newark system in North Carolina and the

first authentic avian relics, those of *Archæopteryx*, already a long way along the road to avian perfection, coming as it does from the Middle Jurassic, would surely imply birds in some stage of their evolution during Newark time.

Professor C. R. Eastman, in a characteristically excellent paper (1911, p. 28), gives the following summary :

"List of Fossil Fishes occurring in the 'Newark' or Upper Triassic Rocks of Eastern North America. [In this list the names of those species occurring in the Connecticut valley are denoted by an asterisk.]

Crossopterygii

Family Cœlacanthidæ

1. **Diplurus longicaudatus* Newberry

Actinopterygii

Family Catopteridæ

2. * *Catopterus gracilis* J. H. Redfield
3. * *Catopterus redfieldi* Egerton
4. *Dictyopyge macrura* (W. C. Redfield)

Family Semionotidæ

5. **Acentrophorus chicopensis* Newberry
6. **Semionotus agassizi* (W. C. Redfield)
7. *Semionotus brauni* (Newberry)
8. *Semionotus elegans* (Newberry)
9. **Semionotus fultus* (Agassiz)
10. *Semionotus gigas* (Newberry)
11. *Semionotus lineatus* (Newberry)
12. **Semionotus micropterus* (Newberry)
13. **Semionotus ovatus* (W. C. Redfield)
14. *Semionotus robustus* (Newberry)
15. **Semionotus tenuiceps* (Agassiz)

Family Eugnathidæ

16. **Ptycholepis marshi* Newberry."

This fauna, except for one crossopterygian, is made up exclusively of ganoids and, judging by comparisons made with fish faunas of the Old World, is considered to be "of more or less manifold nature, and corresponds in a general way to the interval between the uppermost Muschelkalk and the basal division of the Keuper in the Mediterranean region."

The fish remains are nearly all from the two general levels of black bituminous shale, which also contain the plant relics, in varying profusion. Rarely are footprints found in juxtaposition to the fishes and never, so far as I am aware, upon the

fish-bearing shales themselves. Geologically, the shale bands are associated with the trap outflows, an anterior bed following immediately upon the anterior trap sheet to a thickness of from 50 to 100 feet and a posterior zone of about 100 feet immediately preceding the posterior trap, the relationship of the shale and trap being in one case the reverse of the other. Geographically, the fish localities are distributed from Turners Falls, Massachusetts, to Lake Saltonstall, New Haven, Connecticut.

The Terrestrial Vertebrates.

Reference has already been made to the great disparity in numbers of actual bone remains as compared with the footprints, and while the number of the latter contained in our museums is so great as to be unrecorded, and many more have been destroyed, the skeletal remains are by no means as rare as is generally supposed, for as a matter of fact no fewer than three genera and five species of dinosaurs, one of a belodon, and two species of aëtosaurs have been described from the Connecticut valley area alone, while the actual number of specimens naturally exceeds this record of forms. Geographically, osseous remains are reported from Greenfield, Belchertown, South Hadley, and Springfield, Massachusetts; and from East Windsor, Ellington, Manchester, New Haven and Simsbury in Connecticut. The footprints occur scatteringly the entire length of the valley from above Turners Falls to New Haven, but the greatest abundance both of separate localities and profusion of species and specimens is in the more northern portion of the area, specifically around Turners Falls and near South Hadley, Massachusetts. Hitchcock, in the "Ichnology of Massachusetts," enumerates no fewer than 38 quarries for fossil footprints, and a very few localities have been discovered since that time. The geological sequence of the various fossil and footprint localities is shown in the appended table.

The creatures known from the bones are as follows:—

Class Reptilia

Order Parasuchia Huxley

Suborder Aëtosauria Nicholson and Lydekker (=Pseudosuchia Zittel)

Family Aëtosauridæ

Stegomus arcuatus Marsh

From the lower series of granitic, coarse sandstones (Fair Haven arkose), New Haven, Conn.

Stegomus longipes Emerson and Loomis

From the upper series of sandstones (Longmeadow sandstone), Longmeadow, Mass.

Suborder Phytosauria Baur

Family Phytosauridæ McGregor

Rhytidodon (*Belodon*) *validus* Marsh

From the lower series of granitic, coarse sandstones, of Simsbury, Conn.

Order Dinosauria Owen

Suborder Theropoda Marsh (Carnivorous Dinosaurs)

Superfamily Megalosauria Baur

Family Anchisauridæ Marsh

Anchisaurus (*Megadactylus*) *polyzelus* (E. Hitchcock, Jr.)

From the upper series of sandstones and shales (Longmeadow sandstone), Springfield, Mass.

Anchisaurus colurus Marsh

From the upper series, Manchester and East Windsor, Conn.

Anchisaurus solus Marsh

From the upper series of Manchester.

Ammosaurus major Marsh

From the upper series of Manchester.

Superfamily Compsognatha Huxley

Podokesaurus holyokensis Talbot

From the upper series (Longmeadow sandstone), South Hadley, Mass.

These forms may be briefly described as follows:—

The Parasuchia were reptiles, more or less lizard-like in form with an outer armor consisting of bony plates which are in part segmentally arranged. They were distinguished from the later crocodiles mainly by the position of the internal nares (nostrils), which were normal and not shifted to the rear by the growth of a secondary bony palate. In the modern crocodiles this is a device to prevent strangling while devouring prey under water by bringing the nasal chamber in direct communication with the glottis. The Parasuchia were both aquatic, fish-eating forms and, in the aëtosaurs, truly terrestrial reptiles though still doubtless of carnivorous habits.

Stegomus arcuatus Marsh is represented by the impression of the dorsal armor only, showing it to have consisted of narrow transverse plates extending from the mid-line well across

FIG. 1.

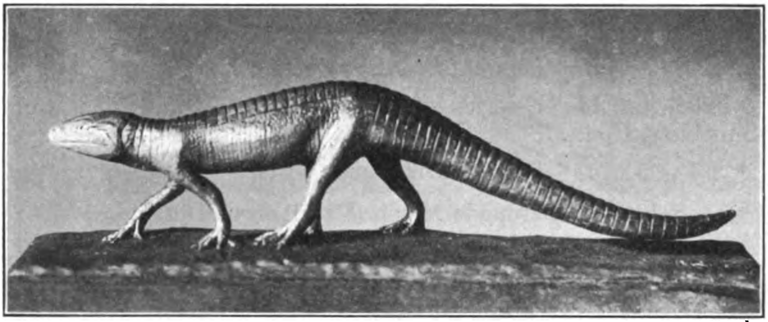

FIG. 1. Restoration of *Stegomus longipes* Emerson and Loomis. About two-sevenths natural size. Modeled by R. S. Lull.

the back, flanked by smaller plates along the sides, each series overlapping its successor behind. The animal was estimated

FIG. 2.

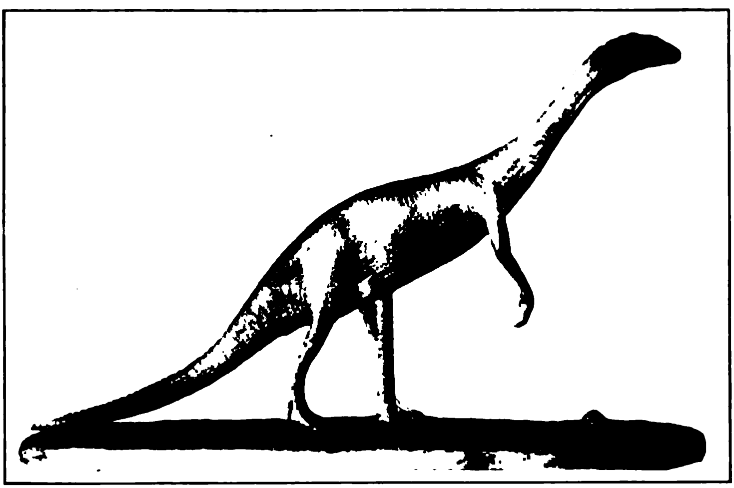

FIG. 2. *Anchisaurus colurus* Marsh. Right side of the statuette showing the flesh. One-twenty-first natural size. Modeled by R. S. Lull.

by Professor Marsh to have been of "moderate size, probably eight or ten feet long." It is preserved in the Yale University Museum.

Stegomus longipes Emerson and Loomis is much more completely known, as nearly the entire armor from neck to rump is preserved as well as the skull, sacrum, and remains of the limb-bones. The latter give indication of long slender legs, the whole organism indicating an animal of small size with limbs of such character as to indicate most strongly a correlation with certain abundant footprints of the genus *Batrachopus* in which the long step and narrow trackway indicate a mammal-like gait though the feet themselves were still typically reptilian. A restoration of *Stegomus longipes* is here shown

FIG. 3.

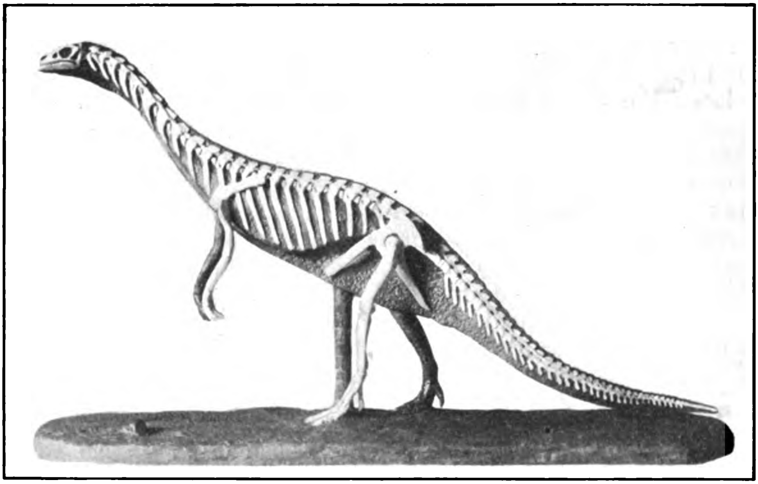

FIG. 3. *Anchisaurus colurus* Marsh. Left side of the statuette showing the skeleton. One-twenty-first natural size. Modeled by R. S. Lull.

(fig. 1), the original specimen being preserved in the museum of Amherst College.

The specimen of *Rhytidodon validus* described by Marsh as *Belodon* is much more meagre, consisting as it does of a single incomplete scapula. It pertains, however, to a very well-known genus, abundant remains of which have been found elsewhere than within the valley limitations, so that the entire character of the animal is approximately known. This creature was of decidedly more crocodile-like aspect, being comparable to the modern gavials which inhabit the large rivers of India, with their long attenuated snout and slender conical teeth. *Rhytidodon* also doubtless resembled the gavial in its fish-eating habits, and the finding of such remains at Simsbury,

Connecticut, implies the presence during early Newark time of a large river or fresh-water lake containing sufficient fish for the maintenance of animals which may have attained the length of a dozen feet. The original specimen of *Rhytidodon validus* is preserved in the Yale Museum.

The Connecticut valley dinosaurs, known from their osseous remains, are all carnivores, but within that group, the Theropoda, two sorts are represented, the heavier, more powerfully aggressive anchisaurs and the slender, swift-running podokesaur, representing the two main phyla of the suborder. The anchisaurs, represented by two genera and four species, were animals of fairly robust proportions, especially *Ammosaurus major*, bipedal though with fore-limbs proportionately larger than in the carnivores of later geologic time, and still well fitted for grasping their prey. There is no evidence, however—and their footprints are known by the hundreds—that they ever placed the hands upon the ground even while resting. The teeth in the skull of *Anchisaurus colurus* are not of the piercing and cutting type seen in the larger, more aggressive carnivores known elsewhere, but are somewhat spatulate, amply sufficient, however, for the feebler reptilian and amphibian creatures which doubtless formed their prey. The light, hollow bones, together with complete bipedalism, imply swift movement over a wide range of territory.

Of the known anchisaurs *Anchisaurus solus* is the smallest with an estimated length of about 3½ feet. *A. colurus* reached 7 feet, and *A. polyzelus* was of nearly equivalent size, the former being slightly the larger, while *Ammosaurus major* was an animal of perhaps 8⅔ feet in length. A restoration of *Anchisaurus colurus*, both skeleton and flesh, is here shown (figs. 2, 3).

With the exception of the type of *Anchisaurus polyzelus*, which is preserved at Amherst College, the Yale Museum contains all the known material pertaining to this group.

Podokesaurus holyokensis represents the latest discovery of dinosaurian remains in the Connecticut valley region. It was found by Miss Mignon Talbot during 1910. This animal, known from the entire skeleton of the trunk and much of the tail and limbs but unfortunately lacking the head and anterior portion of the neck, has been restored by the writer (fig. 4) as a long-limbed type with an excessively long and slender tail. The head is restored from that of *Compsognathus* of the middle Jurassic of Bavaria, but the rest is based almost without exception upon the skeleton. The estimated length of *Podokesaurus* is 3¾ feet.

Podokesaurus was essentially a slender, cursorial animal, carnivorous in habits, but from the very slenderness which

gave it such celerity of movement necessarily confined to feeble prey of which the various footprints manifest so great an abundance. That it was related to the group represented

Fig. 4.

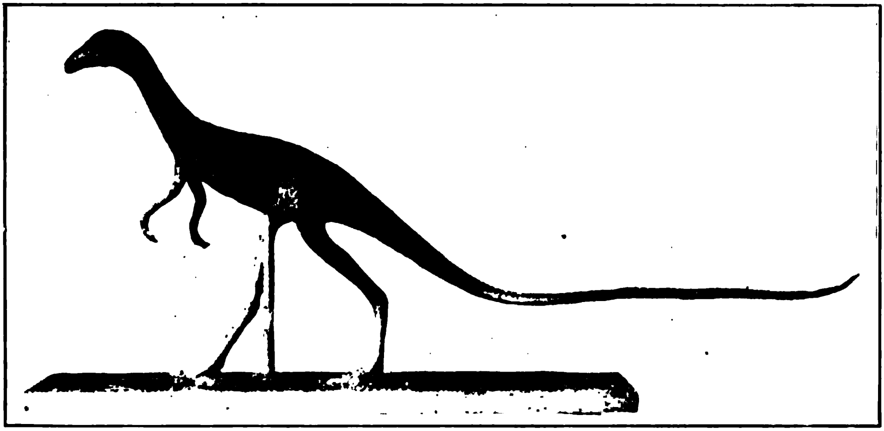

Fig. 4. *Podokesaurus holyokensis* Talbot. Restoration about one-tenth natural size. Modeled by R. S. Lull.

later by *Ornitholestes* from the Morrison and *Ornithomimus* from the close of the Cretaceous seems certain; in fact, I see

Fig. 5.

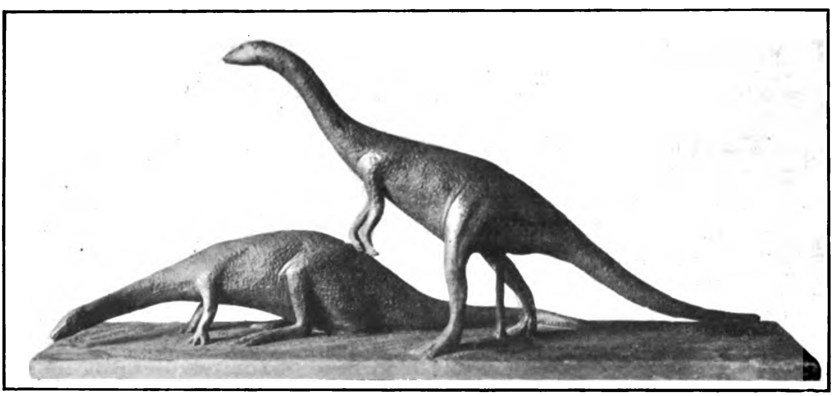

Fig. 5. *Anomœpus scambus* Hitchcock. Restoration of a plant-feeding dinosaur, based upon footprints and the skeleton of *Hypsilophodon foxii* from the British Wealden. About one-fourteenth natural size. Modeled by R. S. Lull.

no feature to debar it from a more or less direct ancestry to its American successors in time.

The Vertebrate Footprints.

The vertebrate tracks are so numerous and so varied withal that the reader is referred to another extract of the Connecticut valley memoir, to appear shortly, for the list with a brief diagnosis of each of the several genera.

They represent cursorial quadrupedal forms similar to *Stegomus*, and dinosaurs both carnivorous and herbivorous as well. Of the former some are very large, indicating animals of at least 27 feet provided the proportions were those of *Allosaurus*, for instance, of the Morrison, while on the other hand there are tracks of such extreme delicacy among the bipedal group that the application of the term dinosaur or "terrible lizard" to such as made them seems absurd. There are also the trails of occasionally erect forms and of true quadrupeds, some doubtless of lizard- or salamander-like shape, but all of these are of small size as compared with the dinosaurian footprints.

Geologically the first known footprints are reported from the anterior shales and are all apparently referable to carnivorous dinosaurs. The posterior shales are of interest in that here are found the first plant-feeding dinosaur tracks in the Newark rocks. It is not until the upper series of sandstones and shales is reached that the great profusion of tracks is manifest, not that the animals were necessarily any more numerous, but that the acme in the perfection of track preservation for which this region is so noted was reached.

In all the total number of footprint genera is 43 while the species exceed this, there being no fewer than 98 all told.

Résumé.

The story of the Connecticut valley, as the evidence at hand now reveals it, may be summarized as follows:

Far back in the remote Triassic period, when the Age of Reptiles was yet young, there were laid down in a gradually deepening trough in the older rocks the great accumulations of gravels, sands, and clays, interbedded with vast lava sheets, which constitute the sediments of the Newark system. The older notions of the submarine or estuarine origin of these rocks have been abandoned on the ground of their containing no relics whatever of marine or even brackish water origin, and of the difficulty of accounting for the deposition of the sediments except by tidal currents of far greater transporting power and governed by laws of movement at variance with

any on earth to-day. On the other hand, evidence seems to point to continental deposits, the result of the ordinary subaërial agencies of winds and rains and rivers, such as require no ingenious straining of nature's laws to account for the accumulation of vast deposits in the course of time. The origin of the sediments was the wasting of the older rocks which formed the limiting highlands on either side of the depression: and the organic remains, all of fresh-water or terrestrial origin, testify to the presence, from time to time at least, of standing bodies of water of considerable extent; of seasonally, if not continually, flowing rivers; and of extensive land areas with slowly drying pools left after the infrequent, but torrential showers characteristic of arid to semi-arid regions of the present day. That there were climatic cycles, such as Huntington (1907, 1911) has observed in the Near East, I have no doubt, and I have reason to believe from the evidence of the fossil vertebrates that the climate during the earlier part of the Newark period may have been less arid than toward its close.

The vegetation bore the mark of antiquity in its monotonous sombre greens, for brilliantly colored flowering plants had not yet appeared, and apparently there was that sparseness and lack of profusion, except locally, which characterizes our great Southwest. The plants were of three main sorts: ferns, cycads, and conifers, looked upon by existing animate life as undesirable food, but which for utter want of a better must have tempted some of the denizens of Triassic time, for we have evidence of mild-mannered herbivores among the rapacious devourers of flesh.

Of the organic remains, those of vegetable origin consist of the impressions and casts of the trunks of trees, some of the latter found at Portland being of such size as to indicate a stream of no mean transporting power; and of the impressions of leaves, twigs, and fruits, occasionally containing a delicate film of carbon which preserves the most intricate detail with wonderful fidelity. Here and there the vegetable remains were of sufficient abundance to influence the production of black bituminous shale bands of 60 to 100 feet in thickness, formed during periods of the accumulation of waters which supported a teeming population of fishes; but never within this area were conditions ripe for the formation of beds of coal such as are found in the Newark strata from Virginia southward.

Animate life left its record rarely in the form of shells or bones, but in marvellous abundance in trails and footprints, some of such clarity of meaning that he who runs may read, others of more difficult and questionable interpretation, yet others exasperating in their baffling obscurity.

Both vertebrates and invertebrates are thus represented. Of the latter the actual fossils are impressions of at least two species of shells, allied to the modern fresh-water Unios, a small crustacean, and a single aquatic insect species, the last occurring in profusion of numbers, and bearing the unique distinction of being the oldest true insect *larva* known. Some of the trails are worm-like as though made by annelids, others show serially repeated footmarks in pairs of fours or sixes or more, indicating the presence of other arthropods than *Mormolucoides*, many of which were doubtless insects, others myriapods, perhaps spiders and scorpions, and fresh-water crustaceans as well. Some of these are small and of wondrous delicacy, others larger than the trails of any insects of fresh-water crustaceans known, which must represent giants among their race.

The fishes, all of the old-fashioned armored sort, have been alluded to as occurring in abundance from time to time in the black shale bands, representing lake deposits with a luxuriant growth of plants.

The terrestrial vertebrate skeletons are all reptilian remains; three those of phytosaurs, remotely related to living crocodiles, and, in one instance at least, economically equivalent to the fish-eating gavials of the Far East. The others are all dinosaurs of average size and representative kinds, neither the largest nor the most specialized which lived during the time of which we speak being known to us. Unfortunately, too, the dinosaurian skeletons were those of contemporaries and, therefore, in themselves throw no direct light upon evolutionary history. Of the five species four are so nearly related as to be of one family and three of one genus, while the other represents a different race, which in its ultimate culmination was far apart from the group for which the others stand, though all were sanguinary devourers of flesh.

The footprints represent two, possibly three, great classes of terrestrial beings. Amphibia of salamandrine form were perhaps present, and doubtless representatives of the more archaic armored stegocephalians as well, though one cannot indicate the track of either with assurance. Of the reptiles, the possibilities of time and place would indicate lizards, turtles, and dinosaurs among the more familiar forms, and these unquestionably were represented in the fauna, and among those less known the Rhynchocephalia, phytosaurs, aëtosaurs, and theromorphs are within the possibilities.

Whether or not birds were present is still a mooted question. The elder Hitchcock considered all of the bird-like tracks unquestionably to have been of avian origin, but the discovery of dinosaurian remains soon swung popular, if not scientific,

opinion to the opposite extreme, and all the tracks were believed to have been made by dinosaurs. I believe, in most instances, this group of footprints is demonstrably dinosaurian. There are some, however, of which I am not so sure; but the only final proof of the existence of Triassic birds will be the actual discovery of their remains, for the earliest yet known, *Archæopteryx*, of the uppermost middle Jurassic, lived thousands of years subsequent to the close of Newark time. If Professor Osborn is right in supposing the pro-avian to have been arboreal, I should not look for its trail over the sands of the Connecticut valley, and I seriously question whether at so remote a time degenerate terrestrial birds had been evolved. On the other hand, the cursorial origin of birds is conceivable, and if true would be possible within the environment we are discussing.

Of the mammals, though known apparently in *Dromotherium* and *Microconodon* from contemporaneous rocks of not very remote geographical locality, we have no record. Their known habitat in the Triassic had a very different climatic and vegetal environment from that of the Connecticut valley; and this, as in the case of birds, would seem to debar them from the limits of this area.

Geologically, the history of Newark times was a tremendous drama of which the prologue speaks of the degradation of the ancient hills and the setting of the stage in the form of an extensive though relatively slight depression, with the establishment of the sediment-bearing drainage from the environing upland. Four great acts, of which the first and last were much the longest, succeed each other in time, separated by interacts of appalling grandeur, when vast sheets of molten rock welled from the depths and spread far and wide, blotting out the old and preparing the stage for newer and different players. Of the sequence of the scenes within the acts, the order is not so surely recorded, since they differed in their position in the valley, in the nature of the sediment in which their record is written and in the forms that peopled the stage. The whole drama is incredibly long as we measure time, for each succeeding day with its dawning, morning hours, high noon, declining sun, and long night added but the smallest increment to the gradually accumulating sediments, though, as has been said, "Neither time nor space flow evenly," and there were tempestuous days whose contribution to the mass made up for the calm passage of those to follow, yet when one thinks of the two and one-half miles of accumulations which these days represent, he can feebly grasp at a realization of the extent of Newark time.

During the long first act, in the course of which were laid

down the six or seven thousand feet of the lower series of granitic, coarse sandstones, we have but little record of the action; but two entrances are recorded, one of which is at New Haven when the heavily armored *Stegomus arcuatus* appears, whose habits we can scarcely conjecture, as the burial of its body in river sediment means little. The second scene at Simsbury is more intelligible because, while part of a shoulder blade only is preserved, it is from the representative of a genus *Rhytidodon* which is almost completely known, hence we are justified in applying the old Cuvierian principle and reconstructing, not only a long-snouted, fish-eating animal from a single bone, but its fish-supporting, aquatic environment as a stage setting as well.

This act closed with the first lava outpouring, the so-called anterior trap, which was followed immediately by the second act, that of the anterior shales, interesting in being ushered in by the first fish- and plant-bearing black shale deposit, followed in the region round about Mount Holyoke and Mount Tom by the first recorded appearance of dinosaurs in the Connecticut valley. Of these *Eubrontes giganteus*, one of the very largest, was among the first, possibly representing a form like the larger genera well known from their bones in the Old World. Others were the larger species of *Anchisauripus*, indicating the presence of *Ammosaurus*-like dinosaurs as well. This second act, with but a thousand or more feet to its credit, was the briefest of all, and the interact following, as befits the middle of the drama, was the most stupendous with the accumulation of the 500 feet of lava which constitutes the main trap sheet.

Act III, during which the posterior shales were laid down, is still more prolific of animate records, for the known footprints not only increase in number, but here for the first time we find those of *Anomœpus* giving the earliest reasonably sure record of the advent of plant-feeding dinosaurs, while that of *Grallator cursorius* shows that accompanying their larger, fiercer brethren were the lighter, more agile dinosaurs of compsognathoid type. This act closed with another scene, during which the plant- and fish-bearing black shales could be accumulated. The relative duration of these posterior shales was somewhat greater than that of the anterior deposition, but was followed by the smallest of all the lava outpourings, that of the posterior trap.

It is only in the final act that the profusion of the cast becomes evident, for at various levels within the 3,500 feet of its accumulations, but notably toward its close, at Portland, around South Hadley, and within and about Turners Falls, are recorded by far the great majority of the known

genera and species of the footprints of the Trias; while equivalent beds, mainly from South Hadley southward to Manchester, Connecticut, have yielded all of the osseous dinosaurian remains. One is impressed with the profusion of trails which imply swift motion, as though conditions were hard and life the antithesis of one of languorous ease, the principal feature which gives rise to the belief of locally increasing aridity of climate.

Here more than in any other act of paleontological history one is conscious of an obscuring drop scene in the middle distance, behind which may be seen with tantalizing clarity the passing and repassing feet of a great host of players: some rapidly, as though impelled by urgent impulse; others slow-moving, ponderous, the like of which the paleontologist has never seen. Occasionally one passes before the curtain and there, while fully exposed to our scientific vision, a tragedy is enacted, for bones are ever symbolical of death; but the footprints are those of creatures in the full tide of life.

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Geologic Section of the Newark System of Connecticut (modified from Schuchert).

Character of sediments	Thickness	Characteristic fossils
Upper series of sandstones and shales with local conglomerates	3,500 ft. +	The great majority of known footprints of all varieties, vertebrate and invertebrate; also *Mormolucoides articulatus*. *Anchisaurus* spp., *Ammosaurus* and *Podokesaurus*, among dinosaurian skeletons. *Stegomus longipes*, skeleton.
Posterior trap sheet	150 ft.	
Black bituminous zone	100 ft.	Plants and fishes
Posterior shales	1,200 ft.	Dinosaur tracks. First plant-feeding dinosaur footprints known. Mt. Tom East, Middlefield, etc.
Main trap sheet	500 ft.	
Anterior shales	1,000 ft.	First known dinosaurian footprints. Carnivores. Mt. Tom West and Mt. Holyoke; Higby, Conn.
Black shales	50 to 100 ft.	Plants and fishes
Anterior trap sheet	250 ft.	
Lower series granitic, coarse sandstone (With intrusive trap sheet, 500–600 feet thick)	5,000 to 6,500 ft.	*Rhytidodon validus*, Simsbury, Conn. *Stegomus arcuatus*, New Haven, Conn. *Estheria* sp. West Holyoke, Mass.
Sandstone	200 to 300 ft.	
Gneisses, schists, and granites Pre-Mesozoic		

ART. XXXV.—*The Oxalate-Permanganate Process for the Determination of Copper Associated with Cadmium, Arsenic, Iron, or Lead;* by H. L. WARD.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccxxx.]

IT has been shown by Peters* in a paper from this laboratory that copper oxalate may be precipitated by oxalic acid with practical completeness from solutions of a copper salt, provided the volume of the liquid is not too great and that the amount of copper present exceeds a minimum value, somewhat dependent on conditions. Still more recently, it has been shown† that the condition of supersaturation, which is responsible for failure in the precipitation of minimum amounts of copper oxalate, may be easily overcome by freezing the solution, by addition of alcohol to the amount of 50 per cent of the solution, and, in a higher degree, by evaporation to dryness or by the addition of large amounts of acetic acid. The best and most convenient procedure for the precipitation of large as well as small amounts of copper oxalate ideal in composition, consists in adding 2 grms. of oxalic acid to 50^{cm^3} or 4 grms. to 100^{cm^3} of the 50 per cent acetic acid solution of the copper salt containing 5 to 10 per cent of nitric acid. The permanganate titration of the washed oxalate, in the presence of sulphuric acid, gives a very accurate determination of the copper.

The present paper is an account of attempts to apply the latter two processes in separations of copper from cadmium, arsenic, and iron, and in the determination of copper after separating the lead as sulphate.

In the experiments of the first part of Table I a standard solution of copper sulphate was treated with one gram of oxalic acid, added in the solid form to the boiling solution of about 50^{cm^3} volume, and the liquid was then evaporated on the steam bath. Extraction was made with the amounts of nitric acid indicated and water to make up a volume of 50^{cm^3}. The liquid was then boiled for 10 minutes in contact with the precipitate and allowed to cool. The oxalate was collected upon asbestos in a perforated crucible and washed carefully with small amounts of water. The crucible with its contents was placed in a beaker and covered with about 200^{cm^3} of hot water, containing 25^{cm^3} of dilute sulphuric acid (1:4), and approximately N/10 potassium permanganate of known standard added to coloration.

* This Journal [4], x, 359.
† Gooch and Ward, ibid. [4], xxvii, 448.

The experiments of the second part of the table were performed similarly, except that the active mass of the oxalic acid was increased by the addition of more of the crystals before extraction. It will be noticed that when the concentration of the oxalic acid is slight, even the smaller amounts of nitric acid cause considerable errors and that these errors increase with the percentage of nitric acid present. When, however, oxalic acid is added nearly to the saturation point of the liquid, the losses are not large and do not increase materially even when very large quantities of nitric acid are used in the extraction. It is evident, also, that about one milligram of copper goes into solution and the process is only accurate up to this amount.

TABLE I.

The Effect of Desiccation and Extraction with Nitric Acid.

Copper taken grm.	Volume at precipitation cm^3	Volume of liquid used in extraction cm^3	Nitric acid cm^3	Oxalic acid grm.	Copper found grm.	Error grm.
			A. Small Amounts of Oxalic Acid			
0·0504	50	50	1	1	0·0497	—0·0007
0·0504	50	50	2	1	0·0492	—0·0012
0·0504	50	50	3	1	0·0487	—0·0017
0·0504	50	50	4	1	0·0479	—0·0025
0·0504	50	50	5	1	0·0469	—0·0035
			B. Large Amounts of Oxalic Acid.			
0·0504	50	50	3	6	0·0495	—0·0009
0·0504	50	50	4	6	0·0495	—0·0009
0·0504	50	50	5	6	0·0491	—0·0013
0·0504	50	50	5	6	0·0495	—0·0009
0·0504	50	50	10	6	0·0486	—0·0018
0·0504	50	50	15	6	0·0486	—0·0018
0·0504	50	50	20	6	0·0487	—0·0017
0·0504	50	50	25	5	0·0491	—0·0013
0·0504	50	50	25	5	0·0491	—0·0013
0·0504	50	50	40	5	0·0494	—0·0010

The Separation of Copper from Cadmium as Oxalate.

It was found that the procedure outlined above does not secure a complete separation of copper from cadmium, as some of the latter element is included with the copper and cannot be dissolved even on treatment with concentrated solutions of hot nitric acid. If, however, nitric acid is added before precipitation, the oxalate of cadmium separates out only on evaporation, when it readily dissolves on treatment with more acid.

The first process used for the separation of copper and cadmium is as follows: To the boiling concentrated solution of the nitrates or sulphates of copper and cadmium, containing 5^{cm^3} of strong nitric acid, is added 4 grms. of crystallized oxalic acid. The solution is evaporated to dryness on the steam bath and the residue is taken up with cold water containing nitric acid, it being unnecessary to heat the acid to bring about the solution of the cadmium. The precipitate is transferred to the perforated crucible by means of the filtrate and washing is done with small amounts of water. The crucible is then placed in a beaker containing about 25^{cm^3} of dilute (1:4) sulphuric acid and 200^{cm^3} of water heated to boiling, and the dissolved oxalate is titrated with permanganate. It is necessary to use a large excess of oxalic acid in the precipitation, for some of it is destroyed by the nitric acid on evaporation to dryness. It will be seen from Table II that when 10 per cent nitric acid is used in extraction, the errors, while all negative, are within permissible limits. On using 20 per cent acid, however, a considerably greater amount of oxalate goes into solution. This process, at best, is not extremely accurate.

TABLE II.

Separation of Copper from Cadmium by Desiccation and Extraction.

Copper present grm.	Cadmium present grm.	Nitric acid on precipitation cm³	Volume at precipitation cm³	Oxalic acid grm.	Liquid used in extraction cm³	Nitric acid used in extraction cm³	Copper found grm.	Error grm.
0·0514	0·01	5	50	4	50	5	0·0507	—0·0007
0·0514	0·06	5	50	4	50	5	0·0506	—0·0008
0·0051	0·10	5	50	4	50	5	0·0048	—0·0003
0·0504	0·10	5	50	4	50	5	0·0502	—0·0002
0·0514	0·10	5	50	4	50	5	0·0508	—0·0006
0·0514	0·20	5	50	4	50	5	0·0508	—0·0006
0·1542	0·20	5	50	4	50	5	0·1537	—0·0005
0·0516	0·30	5	50	4	50	5	0·0507	—0·0009
0·0504	0·10	5	50	2	50	10	0·0488	—0·0016
0·0504	0·10	5	50	4	50	10	0·0494	—0·0010
0·0514	0·20	5	50	4	50	10	0·0500	—0·0014

It has been shown in the previous paper* that copper may be precipitated very completely from solutions of its salts by oxalic acid, provided one-half the volume of the solution consists of glacial acetic acid, and that considerable amounts of nitric acid may be present without causing appreciable error. In separating copper from cadmium by this second process, precipitation is brought about by oxalic acid in a solution one-half

* This Journal [4], xxvii, 448, 1909.

of whose volume is glacial acetic acid containing free nitric acid. The oxalic acid is added in the solid form to the boiling solution and the resulting oxalate allowed to stand over night. Filtration, washing and titration are made in the same manner as in the former method.

It will be noticed that in the first part of Table III, where small amounts of oxalic acid have been used in the precipitation, the results have a tendency to come low, especially when the larger amounts of nitric acid are present. At least 3·5 grm. to 4 grm. of oxalic acid should be used for every 100^{cm^3} of solution, but more causes trouble by crystallizing out. It is then necessary to dissolve the crystals in water, which may cause a slight error due to solubility, or to use the mixture of equal parts water, acetic acid and alcohol recommended by Classen.* When very little copper is present not more than 5^{cm^3} of nitric acid should be added before precipitation. With amounts exceeding 50 mg. 10^{cm^3} should be used to 100^{cm^3} of liquid. A separation may be thus secured from 0·20 grm. of cadmium. With 0·3 grm. of cadmium and 50 mg. of copper it is possible to obtain satisfactory results when the volume on precipitation is increased to 200^{cm^3} If 0·15 grm. of copper is present, even under these conditions, some of the cadmium comes down with the copper. Increasing the volume of nitric

TABLE III.

Separation of Copper from Cadmium by Precipitation from a Solution Containing a Large Amount of Acetic Acid.

Copper present grm.	Cadmium present grm.	Volume at precipitation cm³	Oxalic acid grm.	Acetic acid cm³	Nitric acid cm³	Copper found grm.	Error grm.
0·0051	0·10	50	1	25	5	0·0052	+0·0001
0·0051	0·10	100	2	50	5	0·0045	−0·0006
0·0051	0·10	100	2	50	5	0·0043	−0·0008
0·0253	0·20	100	2	50	10	0·0251	−0·0002
0·0511	0·20	100	2	50	5	0·0512	+0·0001
0·1533	0·20	100	2	50	5	0·1545	+0·0012
0·1533	0·20	100	2	50	10	0·1525	−0·0008
0·0051	0·20	100	4	50	5	0·0049	−0·0002
0·0255	0·20	100	4	50	10	0·0257	+0·0002
0·0510	0·20	100	4	50	10	0·0512	+0·0002
0·1530	0·20	120	3·5	50	10	0·1533	+0·0003
0·0051	0·30	100	4	50	5	0·0053	+0·0002
0·0511	0·30	100	4	50	10	0·0520	+0·0009
0·0511	0·30	200	8	100	10	0·0510	−0·0001
0·1533	0·30	100	4	50	10	0·1556	+0·0023
0·1533	0·30	100	4	50	20	0·1556	+0·0023
0·1629	0·30	200	8	100	10	0·1643	+0·0014
0·1629	0·30	100	4	50	10	0·1636	+0·0007

* Zeitschr. anal. Chem., xviii, 175.

acid present to 20$^{cm^3}$ does not entirely eliminate the error when the volume is kept at 100$^{cm^3}$. Another method, used in the last experiment of the table, is to precipitate in water solution and add the acetic acid afterward to throw out the last traces of copper. This secures a somewhat sharper separation in the case of the larger amounts of the metals.

The Separation of Copper from Arsenic as Oxalate.

In the first attempt to separate copper from arsenic the evaporation process used for cadmium was tried. No nitric acid was added on precipitation, as the arsenic comes down only on evaporation and may be dissolved again. Less nitric acid was also used in the extraction. In the experiments of Table IV the arsenic was present in the form of potassium arsenate, as it was found much easier to make a sharp separation when the arsenic was in the higher condition of oxidation. Even then it was difficult with the larger amounts to bring the arsenic entirely into solution.

TABLE IV.

Separation of Copper from Arsenic by Desiccation and Extraction.

Copper present grm.	Arsenic present as arsenate grm.	Volume at precipitation cm^3	Oxalic acid grm.	Solution used in extraction cm^3	Nitric acid used in extraction cm^3	Copper found grm.	Error grm.
0·0051	0·10	50	1	50	2	0·0047	—0·0004
0·0504	0·05	50	1	50	2	0·0499	—0·0005
0·0504	0·05	50	1	50	2	0·0501	—0·0003
0·0504	0·10	50	1	50.	2	0·0503	—0·0001
0·0504	0·10	50	1	50	2	0·0497	—0·0007
0·0504	0·20	50	1	50	2	0·0498	—0·0006
0·1533	0·20	50	1	50	2	0·1528	—0·0005

On precipitation from a solution containing a large amount of acetic acid according to the procedure before described for cadmium, a very sharp and satisfactory separation was secured. The results of some experiments appear in Table V. In the case of the larger amounts of copper it was found necessary to add nitric acid before precipitation to render the precipitate crystalline and suitable for filtration.

TABLE V.

Separation of Copper from Arsenic by Precipitation in a Solution Containing a Large Amount of Acetic Acid.

Copper present grm.	Arsenic present as arsenate grm.	Volume at precipitation cm^3	Oxalic acid grm.	Acetic acid present cm^3	Nitric acid cm^3	Copper found grm.	Error grm.
0·0051	0·20	100	2	50	0·2	0·0052	+0·0001
0·0051	0·30	100	4	50	0·4	0·0054	+0·0003
0·0511	0·30	100	4	50	0·4	0·0505	—0·0006
0·1530	0·20	100	4	50	10·0	0·1530	±0·0000
0·1533	0·30	100	5	50	10·0	0·1530	—0·0003

The Separation of Copper from Iron as the Oxalate.

To secure the complete precipitation of copper in the presence of iron the first method tried was evaporation to dryness, carried out exactly as in the case of arsenic. No nitric acid was used on precipitation and the residue was extracted with very dilute acid, after the addition in most cases of crystallized oxalic acid other than that used in the precipitation. The results of experiments appear in Table VI. It is plain that when only a moderate amount of iron is present the copper may be estimated with a fair degree of accuracy, but when the iron much exceeds 0·16 grm., the figures show, not an increase due to the inclusion of the oxalate of iron, as would be expected, but a loss in copper due to incomplete precipitation. The filtrate also gives a test for copper. The method, therefore only gives satisfactory results when not more than 0·1 grm. of iron is present.

TABLE VI.

Separation of Copper from Iron by Desiccation and Extraction.

Copper present grm.	Iron present grm.	Volume at precipitation cm^3	Oxalic acid on precipitation grm.	Dilution on extraction cm^3	Nitric acid on extraction cm^3	Oxalic acid on extraction grm.	Copper found grm.	Error grm.
0·0504	0·0393	50	1	50	2	2	0·0500	—0·0004
0·0504	0·0393	50	1	50	2	2	0·0501	—0·0003
0·0504	0·0393	50	1	50	2	2	0·0499	—0·0005
0·0504	0·0786	50	1	50	2	2	0·0499	—0·0005
0·0511	0·1000	50	1	50	5	3	0·0506	—0·0005
0·1533	0·1000	50	1	50	5	3	0·1527	—0·0006
0·0051	0·1572	50	2	50	5	2	0·0036	—0·0015
0·0504	0·1572	50	1	50	2	2	0·0497	—0·0007
0·0504	0·1572	50	1	50	2	2	0·0597	—0·0007
0·1542	0·1572	50	4	50	5	4	0·1524	—0·0018
0·0511	0·2000	50	1	50	5	3	0·0475	—0·0036
0·0511	0·2000	50	1	50	5	3	0·0475	—0·0036
0·0511	0·2000	50	3	50	5	3	0·0491	—0·0020
0·0511	0·3404	50	4	50	5	4	0·0482	—0·0029

The effect of precipitation in a solution containing one-half its volume of glacial acetic acid is shown in Table VII.

It appears that when no nitric acid is present, the errors are positive, indicating that some of the iron comes down with the copper. When, however, the solution contains much free nitric acid, losses appear and these losses increase with the amount of nitric acid present. It is evident, therefore, that the solution should not be strongly acid with both these acids at precipitation.

TABLE VII.

The Separation of Copper and Iron by Precipitation in a Solution Containing Large Amounts of Acetic Acid.

Copper present grm.	Iron present grm.	Volume at precipitation cm^3	Oxalic acid grm.	Nitric acid cm^3	Acetic acid cm^3	Copper found grm.	Error grm.
0·0511	0·100	50	2	..	25	0·0524	+0·0013
0·0511	0·100	100	2	..	50	0·0524	+0·0013
0·0510	0·188	100	4	..	50	0·0514	+0·0004
0·0510	0·188	100	4	2	50	0·0511	+0·0001
0·0510	0·188	100	4	5	50	0·0499	−0·0011
0·0511	0·100	100	2	10	50	0·0475	−0·0036
0·0511	0·100	100	4	10	50	0·0489	−0·0022
0·0510	0·188	100	4	10	50	0·0487	−0·0023
0·0510	0·188	110	4	10	50	0·0468	−0·0042

It appears, however, that when the precipitation is made in a solution just acid with acetic acid and a large excess of this acid is added after cooling to throw out the last traces of copper, the oxalate contains very little iron. The most successful procedure is to treat the solution with potassium hydroxide to faint alkalinity, then to make it just acid with acetic acid to precipitate at the boiling temperature with a large excess of oxalic acid. After cooling, about two volumes of acetic acid are added and the oxalate allowed to settle over night. Filtration and titration are made in the usual manner. Results of this procedure are given in Table VIII.

TABLE VIII.

Separation of Copper from Iron by Precipitation in Nearly Neutral Water Solution with Subsequent Addition of Acetic Acid.

Copper present grm.	Iron present grm.	Volume at precipitation cm^3	Oxalic acid grm.	Acetic acid added cm^3	Copper found grm.	Error grm.
0·0051	0·31	50	6	100	0·0049	−0·0002
0·0051	0·45	50	6	100	0·0046	−0·0005
0·0543	0·15	50	6	100	0·0544	+0·0001
0·0543	0·21	50	6	100	0·0542	−0·0001
0·0543	0·31	50	6	100	0·0546	+0·0003
0·0543	0·45	100	12	200	0·0538	−0·0005
0·1629	0·45	50	6	100	0·1649	+0·0020
0·1629	0·45	100	12	200	0·1629	±0·0000

Should much free acid be present originally it should be removed by evaporation before neutralizing the remainder with the potassium hydroxide; and if potassium oxalate crystallizes out, as may happen if much potassium salt is present with the large amount of oxalic acid, it is best dissolved in a mixture of

alcohol, water, and acetic acid in equal parts. When very large amounts of iron are present it is more satisfactory to increase the dilution on precipitation to 100$^{cm^3}$. It is necessary in all cases to have present a very large excess of oxalic acid to secure the complete insolubility of the copper.

Peters found that when potassium nitrate was present in the water solution of a copper salt, all the copper was not thrown down by oxalic acid. It becomes desirable, therefore, to ascertain whether copper oxalate is completely insoluble in the presence of commonly occurring salts, when one-half the solution consists of acetic acid. The results of experiments shown in Table IX show clearly that the separation of the oxalate is complete even when very small amounts of oxalic acid are used. The potassium salts were chosen in preference to the sodium salts because potassium oxalate is much more soluble in water and is therefore less likely to crystallize out in the course of an analysis. Ammonium salts may not be present, as a soluble double oxalate is formed, which is stable in the presence of a large amount of free acetic acid.

In the experiments detailed in the last division of the table concentrated hydrochloric acid was neutralized with potassium hydroxide and acetic acid added before precipitation.

TABLE IX.

Effect of Salts on the Precipitation of Copper Oxalate in the Presence of Acetic Acid.

Copper present grm.	Salt present grm.	Volume at precipitation cm³	Oxalic acid grm.	Acetic acid cm³	Copper found grm.	Error grm.
			KNO_3 present.			
0·0501	1·0	100	1	50	0·0504	+0·0003
0·0501	3·0	100	1	50	0·0504	+0·0003
			K_2SO_4 present			
0·0501	1·0	100	1	50	0·0500	−0·0001
			KCl present			
0·0050	2·0	100	1	50	0·0045	−0·0005
0·0250	2·0	100	1	50	0·0246	−0·0004
0·0501	1·0	100	1	50	0·0501	±0·0000
0·0501	3·0	100	1	50	0·0501	±0·0000
	HCl cm³	HCl neutralized with KOH				
0·0511	1	100	1	50	0·0513	+0·0002
0·0511	2	100	1	50	0·0510	−0·0001
0·0511	3	100	1	50	0·0511	±0·0000
0·0511	5	100	1	50	0·0501	−0·0010
0·0511	3	100	1	50	0·0511	±0·0000
0·1002	5	150	1	100	0·1001	−0·0001

The Determination of Copper Associated with Lead.—The oxalate of lead, though fairly soluble in nitric acid, shows a tendency to be included in the precipitation of an oxalate which is insoluble in that acid. For this reason it was found impossible to separate copper from lead as oxalate, even in a solution very strongly acid with nitric acid. It has been shown in a previous paper* that copper oxalate is insoluble in a 10 per cent solution of sulphuric acid containing one-half its volume of acetic acid and a large excess of oxalic acid. The method proposed, therefore, is to add to a solution of lead and copper as nitrates an equal volume of acetic acid and then from 3 to 5^{cm^3} of sulphuric acid. Under these conditions the lead is completely precipitated as the sulphate and may be filtered off and weighed as such. The filtrate is then evaporated somewhat, a little more acetic acid added and the copper estimated as the oxalate in the usual manner. The results are shown in Table X.

TABLE X.

The Separation of Copper and Lead. Both determined.

Copper present grm.	Lead present grm.	Sulphuric acid cm³.	Acetic acid cm³.	Volume at precipitation cm³.	Oxalic acid grm.	Copper found grm.	Error copper grm.	Lead found grm.	Error lead grm.
0·0511	0·0500	3	50	110	2	0·0513	+0·0002	0·0499	−0·0001
0·0511	0·1000	5	50	100	2	0·0508	−0·0003	0·0996	−0·0004
0·0511	0·1000	5	50	100	2	0·0508	−0·0003	0·0997	−0·0003

Since the lead sulphate does not interfere with the permanganate titration, it is possible, as shown in Table XI, to estimate

TABLE XI.

Determination of Copper in Presence of Lead. Lead not determined.

Copper present grm.	Lead present grm.	Sulphuric acid cm³.	Acetic acid cm³.	Dilution cm³.	Oxalic acid grm.	Copper found grm.	Error grm.
0·0511	0·10	5	50	100	2	0·0508	−0·0003
0·1533	0·20	5	50	100	2	0·1527	−0·0006
0·1533	0·20	5	50	100	2	0·1530	−0·0003
0·0511	0·25	5	50	100	2	0·0511	±0·0000
0·1086	0·25	5	50	100	4	0·1081	−0·0005
0·0051	0·30	5	50	100	4	0·0052	+0·0001
0·0511	0·30	5	50	100	4	0·0508	−0·0003
0·0543	0·30	10	50	100	4	0·0537	−0·0006
0·1022	0·30	10	50	100	2	0·1018	−0·0004
0·0511	0·40	3	50	100	2	0·0509	−0·0002

* This Journal [4], xxvii, 448, 1909.

the copper as oxalate by precipitation and titration without first filtering off the sulphate of lead. In this case the sulphate is precipitated as before, the solution heated to boiling and oxalic acid added. The sulphate and oxalate are then filtered off together, heated to boiling with dilute sulphuric acid and the oxalate titrated with permanganate.

Summary.

It has been shown in this paper that copper may be estimated in the presence of cadmium by precipitation as oxalate, in the presence of nitric acid and subsequent evaporation to dryness, the residue then being extracted with nitric acid, and the oxalate filtered off and titrated with potassium permanganate. A still more accurate determination is obtained by precipitation of the oxalate in the presence of a large amount of free acetic acid and small amounts of free nitric acid.

Copper may be separated from arsenic in the higher condition by the same methods as are applicable in the presence of cadmium.

Copper may be separated from small amounts of iron by desiccation of the oxalate in the presence of nitric acid and extraction with dilute nitric acid. A better method and one more universally applicable is to precipitate the copper by adding oxalic acid to the water solution of the salts of iron and copper and adding two volumes of acetic acid to separate the small amount of copper remaining in solution.

Copper associated with lead may be estimated by first precipitating the latter metal with sulphuric acid in a solution containing a large amount of free acetic acid and then throwing out the copper by oxalic acid (either before or after filtration), and determining the copper by titration in the usual manner.

ART. XXXVI.—*On Solid Solution in Minerals. II.—The Chemical Composition of Analcite;* by H. W. FOOTE and W. M. BRADLEY.

THE mineral analcite is the most important normal metasilicate among the zeolites and occurring, as it does, in excellent crystals, its chemical composition has been the subject of repeated investigations. The formula which has been derived from the analyses, and which is commonly accepted, is $Na_2Al_2(SiO_3)_4.2H_2O$. A consideration of the ratios derived from many analyses will show, however, that this formula is not in good agreement with the facts. This is well illustrated in Table I, in which the ratios of all the analcite analyses given in Dana's Mineralogy have been calculated.

TABLE I.

Ratios obtained from Analyses of Analcite given in Dana's Mineralogy.

	SiO_2	Al_2O_3, etc.	Na_2O, etc.	H_2O
No. 1	4·70	1·16	1·00	2·37
2	4·30	1·07	"	2·15
3	5·35	1·23	"	1·62
4	4·39	1·11	"	2·22
5	4·39	1·01	"	2·30
6	4·17	1·06	"	2·17
7	4·25	·94	"	2·08
8	4·26	1·14	"	2·25
9	3·89	·99	"	1·96
10	3·77	·97	"	2·14
11	3·67	·97	"	1·91
12	3·57	·93	"	1·81
13	3·74	1·02	"	1·94
14	4·05	1·07	"	2·10
15	4·49	1·09	"	2·49
16	4·00	1·00	"	2·04
17	4·15	·98	"	2·14
18	4·27	1·01	"	2·15
19	3·76	·97	"	2·00
20	4·48	1·14	"	2·36
21	4·02	1·01	"	2·03
22	4·03	1·00	"	2·00
23	4·11	1·07	"	2·14

It is impossible to judge of the value of many of the analyses whose ratios have just been given, for in the original descriptions there is usually either no statement made regarding the quality of the material analyzed or the analysis was primarily undertaken to show that analcite was a constituent of certain

rocks. An analysis by Hillebrand,* No. 18 in the table, and another by Clarke & Steiger,† not quoted by Dana, appear to be among the best that have been made. Their results, and the ratios derived from them, are given below:

Analysis by Hillebrand.

	Per cent	Ratio
SiO_2	55·81	4·27
Al_2O_3	22·43	1·01
Na_2O	13·47	1·00
H_2O	8·37	2·15

Analysis by Clarke and Steiger.

	Per cent	Ratio
SiO_2	57·06	4·82
Al_2O_3	21·48	1·07
Fe_2O_3	·13	
CaO	·16	1·00
Na_2O	12·20	
H_2O	8·96	2·53

A glance at all the ratios given above will show that the ratio between soda and alumina is nearly 1 : 1, but that silica and water vary largely from the ratios 4 and 2 demanded by the formula. In Table I the ratio for silica is greater than 4·2 in ten cases, it is less than 3·9 in six cases, and it is between 4 and 4·2 in only seven cases. Similar irregularities are true as regards the ratio for water. Clarke and Steiger,‡ in commenting on their analysis given above, state: "It is at once evident . . . . . . that our sample of the mineral varies notably in composition from the requirements of theory. The silica is 2½ per cent too high while alumina and soda are correspondingly low. No probable impurity and no presumable errors of manipulation can account for so great a divergence. The variations are large enough, common enough and regular enough to command attention." These investigators have suggested that the mineral is an isomorphous mixture of ortho- and trisilicate, the formula of which can be reduced to the simple expression $NaAlX.H_2O$ in which X represents $n SiO_4 + m Si_3O_8$. This modification, however, does not take account of the water, which appears to be as variable as silica.

The evidence to be gathered from the data which have been given points on the whole to a case of variable composition, such as was previously found in the case of nephelite§ and which can be explained by assuming solid solution. Consider-

* Bull. U. S. Geol. Surv., xx, 27, 1885.
† This Journal [4], viii, 251, 1899.
‡ Loc. cit.
§ This Journal [4], xxxi, 25, 1911.

ing the uncertain quality of many of the analyses, however, we have undertaken a new series.

The material used in the analyses, which will be given below, fulfilled two conditions: it was of ideal quality and it came from widely different localities. All the specimens were well-crystallized and all were colorless or translucent, with one exception, that from the Kerguelen Islands, which was milk-white. The attempt was made to obtain samples from localities which had furnished material for the analyses giving ratios less than 4 for silica, as quoted in Table I, but we were not successful. In some cases, the crystals required no special treatment in order to prepare a sample suitable for analysis. In others, where small glassy crystals had been removed from the rock, a thin layer of foreign matter would usually adhere. To entirely free the crystals from this substance, it was found necessary to crush them and after sifting the fragments to a uniform size, to treat them with heavy solution.

Microscopic examination of all the samples prepared for analysis proved them to be free from inclusions and to have a perfectly homogeneous glassy structure. In several cases, the specific gravity of the mineral was obtained from that of the heavy solution, while in others the ordinary method with a balance was used. The results obtained were as follows:

TABLE II.—Specific Gravity of Analcite.

No.	Locality	Specific gravity
1.	Two Islands, N. S.	2·254
2.	Cyclopean Is.	2·260
3.	Kerguelen Is.	2·257
4.	Victoria, Australia	2·219
5.	Michigan, U. S. A.	2·223
6.	Montreal, Can.	2·231

It seems desirable to give at least a brief outline of the methods of analysis, although the mineral is a simple one from an analytical standpoint. At the very outset it may be stated that great care was exercised in regard to the purity of the reagents, and platinum vessels were used wherever possible. The mineral being readily decomposed by hydrochloric acid made it possible to omit the ordinary fusion with sodium carbonate and thus obviate the use of a solid reagent at this point. Two evaporations were made to render silica insoluble, which was treated in the ordinary manner. It may be stated that the specimen from the Kerguelen Islands, which was milk-white in color, decomposed with separation of silica and also with the formation of gelatinous silica when treated with hydrochloric acid. In all other cases the mineral decomposed only with separation of silica. Alumina was precipitated by ammonia,

and after igniting and weighing was fused with potassium bisulphate in order to make a volumetric determination of iron possible. Calcium was absent in all cases, and not more than the merest trace of magnesium was found. Alkalies were determined by a Smith fusion, and water by ignition. The analyses and the ratios calculated from them are given below (Table III).

TABLE III.—New Analyses of Analcite.

1. Two Islands, N. S.

	I	II	Average	Ratio
SiO_2	55·90	55·90	55·90	4·46
Al_2O_3	22·38	22·41	22·40	1·06
Fe_2O_3	·11	·12	·11	
K_2O	·06	----	·03	1·00
Na_2O	12·85	12·96	12·91	
H_2O	8·38	8·33	8·35	2·24
	99·68	99·72	99·70	

2. Cyclopean Islands.

	I	II	Average	Ratio
SiO_2	54·39	54·42	54·41	4·16
Al_2O_3	23·73	23·52	23·62	1·07
Fe_2O_3	·12	·13	·12	
K_2O	·12	·11	·12	1·00
Na_2O	13·30	13·42	13·36	
H_2O	8·24	8·25	8·24	2·12
	99·90	99·85	99·87	

3. Kerguelen Islands.

	I	II	Average	Ratio
SiO_2	54·49	54·86	54·68	4·18
Al_2O_3	23·23	23·43	23·33	1·05
Fe_2O_3	·15	·14	·14	
K_2O	----	·03	·02	1·00
Na_2O	13·37	13·57	13·47	
H_2O	8·46	8·47	8·46	2·17
	99·70	100·50	100·10	

4. Victoria, Australia.

	I	II	Average	Ratio
SiO_2	55·09	55·02	55·06	4·29
Al_2O_3	22·84	22·87	22·85	1·05
Fe_2O_3	·15	·15	·15	
MgO	·25	·10	·17	1·00
Na_2O	13·20	13·16	13·18	
H_2O	8·32	8·44	8·38	2·19
	99·85	99·74	99·79	

5. Michigan, U. S. A.

	I	II	Average	Ratio
SiO_2	56·53	56·43	56·48	4·45
Al_2O_3	21·85	22·42	22·13	1·02
MgO	·26	·16	·21	
K_2O	·09	·13	·11	1·00
Na_2O	12·92	13·16	13·04	
H_2O	8·37	8·41	8·39	2·21
	100·02	100·71	100·36	

6. Montreal, Canada.

	I	II	Average	Ratio
SiO_2	56·96	56·72	56·84	4·61
Al_2O_3	22·75	22·88	22·81	1·09
Fe_2O_3	·25	·19	·22	
K_2O	·16	·21	·19	1·00
Na_2O	12·67	12·72	12·69	
H_2O	8·23	8·31	8·27	2·25
	101·02	101·03	101·02	

The summary of the ratios obtained in these six new analyses is given below. There are included also the ratios from the analyses by Hillebrand (No. 7) and by Clarke and Steiger (No. 8), which appear to be as good as any that have been made.

TABLE IV.—Summary of Ratios.

No.	SiO_2	Al_2O_3, etc.	Na_2O, etc.	H_2O.
1.	4·46	1·06	1·00	2·24
2.	4·16	1·07	"	2·12
3.	4·18	1·05	"	2·17
4.	4·29	1·05	"	2·19
5.	4·45	1·02	"	2·21
6.	4·61	1·09	"	2·25
7.	4·27	1·01	"	2·15
8.	4·82	1·07	"	2·53

The ratios in Table IV confirm the general statement which was made from a consideration of old analyses, that the accepted formula is not in good agreement with the facts of analysis. Silica and water both show ratios which are always higher than the formula requires, and in most cases are very much higher. The ratio $Na_2O : Al_2O_3$ is nearly 1 : 1. The average of all results 1 : 1·05. The ratio $H_2O : SiO_2$ is very close indeed to 1 : 2. Considering the low molecular weight of water, this ratio is as close as could be expected. The average is 1 : 1·97. To sum up the matter, soda and alumina on the

one hand, and silica and water on the other, show simple constant ratios, but there is no ratio either simple or constant between alumina (or soda) and silica (or water). The case appears to be very similar indeed to that of nephelite,* in which the ratio of soda to alumina was simple while their ratio to silica varied largely. The results can be accounted for very simply by assuming in analcite that the excess of water and silica over the amount corresponding to the simple ratios is due to solid solution. The formula of analcite can then be written $Na_2Al_2(SiO_3)_4.2H_2O.xH_2Si_2O_5$. The point must be emphasized that this does not mean that the compound $H_2Si_2O_5$ as such is necessarily present in solid solution. The real components, for instance, may be $Na_2Al_2(SiO_3)_4.2H_2O$ and $Na_2Al_2Si_6O_{16}.3H_2O$. Other possible components may also be chosen. There is no possible way, at the present time, of deciding definitely in regard to the actual components, and furthermore, this seems unnecessary. The facts all point to a case of solid solution of the unusual type found in nephelite where there appear to be isomorphous relations existing between chemical compounds of very different type, and these facts are sufficiently well expressed in the formula as it has been written above.

In deriving the formula, we have used only the eight ratios given in Table IV, six of which are calculated from our own analyses. As shown in Table I, a number of analyses have been made in which the silica ratio is considerably below the ratio number 4, and these cannot be represented by the formula given above. We were unable to obtain any specimens of analcite giving these low ratios and it is impossible to judge of the accuracy of the analyses and the quality of the material used in cases where these low ratios have been found. Until it can be demonstrated that such cases actually occur in pure analcites, we prefer to leave the formula as given. If the occurrence of the low ratios is proved, a slight change in the components chosen will take account of it.

It is interesting to note that the water in analcite† as well as most of the other zeolites‡ does not behave like ordinary water of crystallization. The vapor pressure at a given temperature does not remain constant as the substance is dehydrated as, for instance, the vapor of Glauber's salt does, but it continually diminishes, behaving in this respect like the vapor pressure of an amorphous hydroxide such as silicic acid. For this reason, zeolites do not lose a definite number of molecules of water by heating at a certain temperature or through a certain range of

* Loc. cit.
† Friedel, Bull. Soc. Min., xix, 363, 1896; xxii, 5, 1899.
‡ Tammann, Zeitschr. phys. Chem., xxvii, 323, 1898.

temperature, just the reverse of the common behavior of hydrated salts. The explanation has been that water exists in zeolites in a condition of solid solution. Our data, obtained entirely from analyses, supports this view but indicates also that part of the silica is in a similar condition. It would be possible theoretically, however, for the water to behave as ordinary water of crystallization and still have the isomorphous relations derived above.

It is hoped that the deductions advanced in this article may find similar application to other zeolites.

In closing the authors desire to express their thanks to Professor L. V. Pirsson for many valued suggestions. All the material for this investigation was very generously furnished by Professor W. E. Ford from the Brush collection, to whom our thanks are also due.

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New Haven, Conn., Feb. 1912.

ART. XXXVII.—*The Chemical Composition of Nephelite*; by H. W. FOOTE and W. M. BRADLEY.

IN a previous article,* we have shown from a series of analyses that the composition of the mineral nephelite does not correspond to the simple formula $NaAlSiO_4$ but that there is a variable excess of silica beyond the amount required by the formula. Since the material was entirely homogeneous, we showed that the results could be accounted for very simply by assuming that the excess of silica was present in some form in solid solution. We did not attempt to determine the molecular condition of the dissolved silica—whether it was present as albite, for instance, or in any other form (p. 31). Recently, two articles have appeared on the composition of nephelite, one by Schaller† the other by Bowen.‡ Schaller prefers to account for the excess of silica by assuming an isomorphous mixture of nephelite with an hexagonal albite, while Bowen assumes that albite itself accounts for the excess. The presence of kaliophilite with nephelite as an isomorphous mixture of the ordinary type is of course to be assumed but has nothing to do with the excess of silica in the ratios. The difference in our views, then, amounts to this, that we assume silica is pres-

* This Journal, xxxi, 25, 1911. † Wash. Acad. Sci., i, 109, 1911.
‡ This Journal, xxxiii, 49, 1912.

ent in solid solution, leaving the question entirely open as to what form the excess takes. It might, for instance, be present as hexagonal albite as Schaller suggests, just as it might be present in some other form. Schaller, on the other hand, suggests that the particular form which the excess of silica takes is that of an hexagonal albite and Bowen suggests albite and leaves the system of crystallization undecided.

Considering the fact that the greatest uncertainty still prevails in regard to the actual molecular condition of dissolved substances in other types of solution which have been much more investigated, it seems impossible to decide definitely in regard to what molecular aggregates are actually present in nephelite. It appeared to us, when writing the first article (p. 31), as it does now, that it is better to avoid any definite assumption which cannot be proved, regarding the molecular condition of the dissolved silica. Our main point was to show there was an unusual case of solid solution and that it was unnecessary to assume any definite molecular condition for the excess of silica. While it may later be shown that albite actually exists in solid solution, this at present must be regarded as pure conjecture. The albite molecule, if present, would have very peculiar properties, entirely unlike albite as it exists either in pure condition or isomorphous with other feldspars, since nephelite with its excess of silica is completely soluble in N/4 hydrochloric acid. This evidence, however, we recognize fully is not proof that the albite molecule is absent. It cannot be proved either way at present. Hence our point, that it is better to leave the question as to the molecular condition of excess of silica entirely open.

There is one point regarding the amount of silica which nephelite can take up, which needs mention. Bowen states (p. 53): "It is therefore only in the presence of albite itself that nephelites may be expected to be saturated with silica." This is a conclusion which we also drew in our article, but later Bowen states: "The conditions necessary for the saturation of nephelite with albite are so unlikely to occur that it may be safely said that natural nephelites are probably never saturated." It was shown in our former article that three nephelites, which were associated with albite, and one associated with microcline-microperthite, exhibited a constant maximum ratio for silica, and we suggested that this represented the saturation value. The objection could, perhaps, be raised that the nephelite and albite were not formed simultaneously, so that the former was not necessarily saturated. Probably no one will doubt the assertion that if a magma deposits both nephelite and albite together, the former must be saturated with silica at the temperature of solidification. There is plenty of evidence that this process has taken place.

It has been shown by Bayley* and by Morozewicz† that rocks occur where both nephelite and very pure albite must have been formed simultaneously. Morozewicz in particular has shown that in the rock investigated by him, albite crystallized throughout the entire time when nephelite was forming. The nephelite in both rocks was analyzed. It is probable that the material was not as carefully purified as in the cases considered in our former article, since the object was to show that nephelite was present and not to derive its formula. Still, the results should show approximately the limiting ratio for silica, when nephelite is saturated. The ratios calculated from their analyses are as follows:

	Bayley (anal. by Clarke)	Morozewicz
SiO_2	2·15	2·15
Al_2O_3	1·00	1·00
$(Na_2, K_2)O$	·94	·95

The ratios between alumina and alkalies is not as sharp as it should be, perhaps. If, instead of calling alumina 1, the error is allowed to rest equally on alumina and alkalies, which seems fair, the ratios become:

	Bayley (anal. by Clarke)	Morozewicz
SiO_2	2·21	2·21
Al_2O_3	1·03	1·03
$(Na_2, K_2)O$	·97	·98

Whichever way the ratios are calculated, the value for silica comes very close to 2·2, which represents the limiting ratio. The value which we obtained before was 2·21. Since the two values are practically identical, there seems to be no reason whatever for modifying our original statement regarding this ratio. Judging purely by the evidence available, we cannot agree with Bowen 'that natural nephelites are probably never saturated.'

It is to be hoped that the problem may be attacked from the synthetic standpoint in an adequate way. By this means, it will perhaps be shown whether the saturation limit changes appreciably with the temperature of formation, and also whether the potassium content affects this limit to any great extent.

Chemical and Mineralogical Laboratories of the
Sheffield Scientific School of Yale University,
New Haven, Conn., February, 1912.

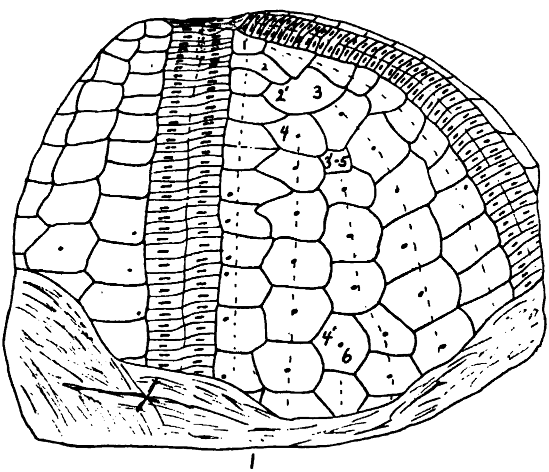
*Bull. Geol. Soc. Amer., iii, 231, 1892. †Min. Petr. Mitt., xxi, 238, 1902.

Art. XXXVIII.—*Description of a new Genus and Species of Palæechinoidea;** by Axel Olsson.

Lepidechinoides gen. nov.

Shape subspheroidal with five ambulacrals and five interambulacral fields. Ambulacrum consisting of two columns of alternately arranged plates imbricating aborally. Each of the ambulacral plates pierced in the middle by a pair of pores set close together. In addition each ambulacral plate is pierced on the extreme ventral surface by a single pore situated on the adjacent ends of the plates. Interambulacrum composed of six columns of adorally imbricating plates. Adambulacral plates

Fig. 1.



Lepidechinoides ithacensis Olsson.

Fig. 1. Side view of specimen enlarged three diameters.
Nos. 1, 2, 3, 4, 5, 6, indicate number of column. 1', 2', 3', 4', initial plates.

slightly smaller than the second column of plates and perforated near ambulacral edge. The interior plates of the interambulacral series more or less hexagonal in shape, except those on the extreme ventral surface, which are small and scale-like. Spines small and striated, dilated at the base.

* The writer is indebted to Prof. H. S. Williams for the many kind suggestions in the preparation of this paper.

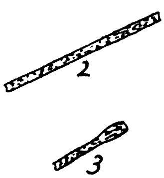
Lepidechinoides ithacensis sp. nov.

Ambulacral plates about three to each of the adambulacral plates bordering them. Each plate perforated in the middle by a pair of pores set close together. Arrangement of plates alternate and imbricated aborally. Interambulacrum consisting of six columns of rather large plates imbricated adorally. Second column of plates larger than the adambulacral plates. Adambulacral plates rhombic or pentagonal in shape and perforated near the ambulacral edge. The inner series of interambulacral plates more or less hexagonal in shape, except those on the extreme ventral surface, which are small and scale-like. These plates pierced in the center except those on the ventral surface. On the oral surface a few of the ambulacral plates are pierced by a pore each on their adjacent ends, but they are confined to this region. Secondary spines small and striated and dilated at the base for attachment.

Length $2{\cdot}5^{cm}$
Width 4^{cm}
Width of ambulacral area 4^{mm}
Width of interambulacral area at middle 17^{mm}

After a careful study of the specimen and of the descriptions and figures of the other three genera in the family, viz.—*Lepidocentrus* Müller, *Perischodomus* McCoy, and *Lepidechinus* Hall, the following points of resemblance and differences were made out. In the imbrication of both areas it approaches *Lepidechinus* and *Perischodomus* and differs from *Lepidocentrus*, in which the ambulacral plates are inflexible. As in *Lepidechinus*, the initial plate 1′ is retained. It is small and irregularly foursided, its ventral apex is sharp and does not appear to have suffered from resorption. This specimen in its possession of only six columns of interambulacral plates is not so highly accelerated in its development as the genus *Lepidechinus* and the species *Lepidocentrus mulleri* Schultze. In *Lepidechinus rarispinus* Hall the introduction of new plates is so rapid that each initial plate touches the next. In *Lepidechinoides* the plates 2, 3, 4 and 5 follow each other rapidly, as shown in figure, but between plates 5 and 6 there are three intervening plates. The exact

Figs. 2, 3.



Figs. 2, 3. Secondary spines enlarged ten diameters.

size and shape of the adambulacrals cannot be ascertained because of the overlapping of the second column of plates; they appear, however, to be rhombic or pentagonal in shape and slightly smaller than the second column of plates, which are undoubtedly the largest of the interambulacrals in this species. The remainder of the interambulacral plates are mainly hexagonal in shape, quite perfectly so near the dorsal surface, but on passing ventrally their edges become rounded. On the extreme oral surface the adambulacral plates are small and scale-like, closely resembling those of *Lepidechinus*. Along a line through the initial plate 4′, the diameters through these plates are as follows: $2{\cdot}75^{mm}$, 4^{mm}, 3^{mm}, 3^{mm}, $3{\cdot}75^{mm}$, and $2{\cdot}75^{mm}$. The number of columns of interambulacrals is variable even in the same genus and may, therefore, only be considered of specific value. The list below gives the range of the number of columns of interambulacrals in the various species in the genera of the family Lepidocentridæ.

(Eu) *Lepidocentrus rhenanus* Schultze 5 I
(Eu) " *mulleri* Beyr 11 I
(Eu) " *eifilianus* Müller unknown
(Eu) *Perischodomus biserialis* McCoy 5 I
" *illinoisensis* Worthern & Miller 5 or more I
Lepidechinus rarispinus Hall 11 I
" *imbricatus* Hall 8 I
Lepidechinoides ithacensis 6 I

In the number of ambulacral plates to each of the adambulacrals there is some variation. As could be expected both in *Lepidocentrus* and *Perischodomus*, in which the adambulacrals are large—being the largest of the interambulacrals—there are many ambulacrals to each of the adambulacrals, while in *Lepidechinus* and in *Lepidechinoides*, in which the adambulacrals are relatively small, the opposite is the case, as shown below.

Lepidocentrus rhenanus Schultze 7–8 A
" *mulleri* Beyr 7–8 A
" *eifilianus* Müller unknown
Perischodomus biserialis McCoy 5–8 or more A
" *illinoisensis* Worthen & Miller
Lepidechinus rarispinus Hall 3–4 A
" *imbricatus* Hall
Lepidechinoides ithacensis 3–4 A

In the above brief summation of a few of the generic characters, it is evident that it is fairly close to *Lepidechinus* Hall. It has for one of its most important differences the perforation of the ambulacral plates in the center and not on the distal

end. Any variation in the ambulacral plates is of great importance and must be considered of at least generic value. *Lepidechinoides* differs also from *Lepidechinus* in its possession of fewer columns of interambulacrals and, more importantly, in having these plates more or less hexagonal in shape and not scale-like as in the latter genus. In this latter character *Lepidechinoides* appears to represent a more primitive form. Jackson in his Studies of Palæechinoidea* shows in reference to *Lepidechinus rarispinus* Hall, that the rhombic and hexagonal shape of the dorsal, or newly added interambulacral plates, have phylogenetic significance, having characters seen normally in less specialized genera and indicating derivation from forms which did not have imbricating plates. Moreover those forms with scale-like imbricating plates are specialized and not primitive types.

From the Devonian of America there are at present three genera and four species of Palæechinodea, representing two families *Lepidocidaridæ* Bather (*Archæocidaridæ* McCoy) and *Lepidocentridæ* Lovén. Vanuxem in his Report of the 3d Geological District, p. 184, mentions some doubtful remains of echinoids from Dryden which he called *Echinus drydenensis.* These specimens were later examined by Hall,† who referred them to the genus *Eocidaris* Desor. They are described as being from the shaly sandstones of the Chemung group, 1,000 feet above the Tully limestone, representing therefor the Enfield shales of the Portage formation. The genus Eocidaris belongs in the family Lepidocidaridæ and with *Xenocidaris clavigera* Schultze of Europe are the only members of the family found below the Sub-Carboniferous. The family *Lepidocentridæ* Lovén is now represented in America by the two genera *Lepidechinus* and *Lepidechinoides* herein described. Of the genus Lepidechinus two species are known, viz., *L. rarispinus* Hall from the Chemung of Pennsylvania, and the Waverly group of Ohio and *L. imbricatus* Hall from the Burlington limestone of Iowa. *Lepidechinoides ithacensis* therefore represents the earliest known echinoid from America although in Europe the genus *Bothriocidaris* Eichwald, of which two species are known, is from the Ordovician. The geological position of all the species in the family Lepidocentridæ is shown below:

Lepidocentrus rhenanus Schultze
" *mulleri* Beyr, middle Devonian of Muhlenberg—near Geroldstein Eifel
" *eifilianus* Müller, Devonian of Nohn Eifel

* Bull. Geol. Soc. of Am., vol. vii, p. 228, 1896.
† 20th Annual Report of State Cab. Nat. Hist. of N. Y., 1868, p. 343.

Perischodomus biserialis McCoy
" *illinoisensis* Worthen & Muller Chester limestone—Pope Co. Ill.
Lepidechinus rarispinus Hall, Chemung Penn. and Waverly—groups of Ohio
" *imbricatus* Hall, Burlington limestone—Burlington Ohio
Lepidechinoides ithacensis Ithaca beds Portage formation N. Y.

The type specimen herein described was found at the University quarry, sometimes called the McCormick quarry, near the lower border of the Cornell campus. This quarry is situated in the zone* characterized by the presence of *Spirifer mesastrialis* and *Cryptonella eudora*, which in the Ithaca region are rarely found above or below these beds. This zone is confined to about twenty-five feet in the center of the Ithaca shale member and of which fifteen feet are exposed in this quarry. It is made up of hard sandstone layers with few shale beds. Fossiliferous layers sometimes occur so thickly filled with fossils as to produce an impure siliceous limestone. On passing eastward this zone is believed to thicken and to be represented in the Chenango valley by the Oneonta sandstone, which there overlies the Ithaca. Besides *Spirifer mesastrialis* and *Cryptonella eudora*, the following fossils are quite characteristic of this zone: *Actinopteria boydi; Camarotœchia eximia; Leiorhynchus mesacostale; Orthoceras bebryx; Gomphoceras tumidum* and *Stictapora meeki* associated with numerous crinoid stems.

Those who desire a more detailed comparison of the genus herein described with the other genera in the family will find the works listed below to be of service:

Hall. Desc. New Spec. Crin., 1861, p. 18.
Hall. 20th Rep. N. Y. State Cab. Nat. Hist., 1868, p. 340, pl. 9, fig. 10.
Keeping, W. Notes on the Paleozoic Echini, Quart. Jour. Geol. Soc., London, vol. xxxii, p. 35, 1876.
Worthen & Miller. Geol. Surv. Ill, vol. vii, 1883, p. 333, pl. 31, fig. 8.
Jackson, R. T. Bull. Geol. Soc. Am., vol. vii, 1896, p. 222–242.
Klem, M. J. A Revision of the Paleozoic Palæechinoidea with complete bibliography. St. Louis Acad. Science Trans., vol. xiv, 1904, pp. 1–98, 6 pl.

Ithaca, N. Y.
Jan. 4, 1912.

* Bull. U. S. G. S., No. 3, p. 17. Watkins Glen-Catatonk folio, U. S. G. S., No. 169, field edition, pp. 64, 65, 92, library edition, pp. 6, 8, 12.

ART. XXIV.—*Relations of the Degree of Metamorphism to Geological Structure and to Acid Igneous Intrusion in the Narragansett Basin, Rhode Island;* by FREDERICK H. LAHEE.

(Concluded from p. 372.)

PART III.

CONTENTS.

PETROLOGY OF THE POST-CARBONIFEROUS ROCKS.

POST-CARBONIFEROUS rocks, intrusive into the sediments of the Narragansett Basin, may be classified from a relative standpoint as basic or acid. To the former category belong a few minette dikes; and to the latter, an extensive series of acid intrusives ranging from granites, through pegmatites, to quartz veins.* These we shall consider in the order named.

* Occasional aplite stringers, belonging to this series, cut the granites, and one or two have been seen to intersect the pegmatite.

Basic Intrusives.

Description.—Dikes of minette have been found in southern Conanicut Island, and of these there are seven instances.* Six cut the fine greenish schists of the Beaver Tail Peninsula (fig. 1, Loc. 23, 14:D) and one cuts the pre-Carboniferous Conanicut granite.

These dikes consist of biotite and orthoclase, together with some microcline, plagioclase, apatite, zircon, titanite, and the secondary minerals, chlorite, calcite, epidote, limonite, and leucoxene.† The biotite, as noted by Collie and Pirsson, reveals evidence of two generations. The older is represented by large idiomorphic plates which are clouded—darkly near the peripheries, but shading off inward—and which contain very fine rutile needles and leucoxene powder. The rutile needles are especially abundant near the edges of the plates. They are arranged in three directions, each at 60° to the others, in planes parallel to the basal pinacoid of the mica. The leucoxene, while sparsely distributed, is more plentiful near the borders of the mica flakes.

Of the younger generation numerous smaller plates are seen and also zones which encircle the earlier phenocrysts. This later form, whether as separate crystals or as border zones, is clear, greenish, and pleochroic, and contains no rutile nor leucoxene. When it occurs surrounding individuals of the first generation, it is in optical orientation with them. Both types have partly or wholly altered to chlorite.

In the section investigated by the writer, there was no parallel orientation of the constituents, and evidences of crushing were slight. In other specimens there is a distinct schistosity. Pirsson‡ attributed the rutile inclusions in the biotite phenocrysts to the influence of the forces which produced this schistosity; but since the biotite crystals are surrounded by zones of unrestrained mica and since the orthoclase grains may abut against or enclose such coated phenocrysts with their rutile needles, we conclude that the anomalous features described for the biotite of the first generation were of magmatic origin.

—*Relations of the minette to the Carboniferous sediments.*—In some places the minette seems to have been intruded into

* Certain ones of these dikes were described by the following writers in the works cited: Foerste, A. F., in Geology of the Narragansett Basin, by Shaler, N. S., Foerste, A. F., and Woodworth, J. B., U. S. G. S., Monog. xxxiii, 1899, p. 232. Pirsson, L. V., in his Geology and Petrography of Conanicut Island, this Journal (3), xlvi, p. 363, 1893. Collie, G. L., in his Geology of Conanicut Island, Trans. Wisc. Acad., x, p. 199, 1894–1895. Crosby, W. O., in his Contribution to the Geology of Newport Neck and Conanicut Island, this Journal, iv, 230, 1897.

† Pirsson gives a chemical analysis: op. cit., p. 375.

‡ Op. cit., pp. 375–376.

joint planes or along the cleavage of the southern Conanicut Carboniferous schists. Or, again, the dikes may cut indiscriminately across such structures. In most cases their thickness is rather variable. Short apophyses may pass from them into the country rock, and small inclusions of the latter may be seen. Exomorphically the schists have been somewhat baked and bleached. The most obvious endomorphic features are the decrease in size of grain toward the contact and the parallelism of the biotite flakes with the walls (flow structure), as noted by Collie* and Pirsson.† Locally these dikes show some folding and schistosity. Veins of massive, milky quartz, sometimes of considerable size, intersect them with sharp contacts.

From these petrographic and structural relations, it would seem that the minette dikes were injected into the Carboniferous sediments before the period of deformation came to an end, yet after schistosity and jointing had been developed in the country rock.‡

—*Summary.*—Dikes of minette (*a*) have been found in a few places in the southern part of Conanicut Island; (*b*) are clearly intrusive into, and are, therefore, later than, the Carboniferous sediments and the pre-Carboniferous Conanicut granite; (*c*) were injected during the general period of deformation of the Carboniferous series; (*d*) are themselves cut by numerous veins of massive, milky quartz.

ACID INTRUSIVES.

Introductory remarks.—We have already mentioned the fact that the granitic rocks in South Kingstown are probably intrusive into the Carboniferous sediments, and that they are not pre-Carboniferous as had formerly been supposed. Since these granites—part of the Sterling series—are especially prominent on Boston Neck (B: 14 and 15, fig. 1), they may be referred to as the 'Boston Neck granite.' They appear to be closely related in origin to the great group of pegmatites and quartz veins which likewise cut the Carboniferous rocks. Herein we shall denote the Boston Neck granite, the pegmatites, and the associated quartz veins by the general term, 'Acid Intrusive Series.'§

* Op. cit., p. 228. † Op. cit.

‡ Pirsson (op. cit., pp. 371–372) said that the schistosity, folding, and faulting in the dikes were caused by dynamic forces acting along north-south lines after intrusion. Collie (op. cit., pp. 228–230) stated that the nearly north-south dikes are schistose because they lie nearly at right angles to the direction of the forces; the east-west ones are folded and faulted.

§ Dr. Loughlin, in his 'Intrusive Granites and Associated Metamorphic Sediments in Southwestern R. I.' (this Journal, xxix, 447, 1910), presents evidences for the genetic relationship of the granites of southwestern Rhode Island, the pegmatites, and the quartz veins. From investigations carried on in the extreme eastern portion of Dr. Loughlin's area and eastward, previous to the publication of the paper just cited, the writer had arrived at similar conclusions, and, certainly in that region where the fields of work overlap, he is in agreement with Dr. Loughlin.

General and theoretical considerations.—As in the discussion of the structural geology of the Basin (Part I of this paper), here also we shall put theory before fact. Accepting the doctrine commonly held to-day, namely, that most pegmatites are of magmatic derivation,* we shall review below certain facts which may assist in the determination of the relations between the Acid Intrusive Series and the Basin sediments.

The importance of the rôle played by catalyzers, or mineralizers, in the crystallization of magmas, and especially of acid magmas, is widely recognized. These mineralizers "have been defined as volatile substances which, without entering into the final composition of minerals, render possible or facilitate their formation and crystallization."† This they do by reducing the viscosity of the magma and by lowering the freezing-points of its constituents.‡ Harker continues, "There is . . . . . no reason for excluding the case in which the mineralizer, or part of it, enters into the mineral as finally constituted."§ Among the chief catalytic agents may be cited fluorine, chlorine, boric acid, carbon dioxide, hydrogen, and water gas.‖

* For summaries of theories for the origin of pegmatite, see the following:

Brögger, W. C., Die Mineralien der Syenitpegmatitgange der südnorwegischen Augit und Nephelinsyenite. Zeitschr. für Kryst., xvi. I Theil, pp. 215–225, 1890. Trans. by N. N. Evans, Can. Record of Sci., vi, pp. 33–46 and 61–71.

Williams, G. H., General Relations of the Granite Rocks in the Middle Atlantic Piedmont Plateau, U. S. G. S., Ann. Rept., xv, p. 657, 1894.

Van Hise, C. R., A Treatise on Metamorphism, U. S. G. S., Monog. xlvii, 1904. Pp. 721–724.

For recent statements on the subject, see:

Harker, A., Natural History of Igneous Rocks, N. Y., 1909.

Iddings, J. P., Igneous Rocks, N. Y., 1909.

Bastin, E. S., Geology of the Pegmatites and Associated Rocks of Maine. U. S. G. S., Bull. 445, 1911.

† Harker, A., op. cit., p. 286.

‡ Daubrée early demonstrated the function of water in promoting the crystallization of anhydrous minerals far below their fusion points. (Daubrée, A., Étüdes synthetiques de Géologie Expérimentale, Paris, 1879, p. 234.)

§ Harker, A., op. cit., p. 287. Thus, muscovite, containing OH, may be regarded by the aid of mineralizers. Nernst, however, defines the process of catalysis as "an increase in velocity of reaction caused by the presence of substances which do not take part in it, although the reaction is capable of taking place without their presence." (Nernst, W., Theoretical Chemistry. London, 1904, p. 566.) See also Doelter, C., Physikalisch-Chemische Mineralogie, Leipzig, 1905, pp. 115 et seq.

Writing on this subject, Bastin suggested the application of Raoult's law to rock magmas "to the extent that magmatic constituents of low molecular weight may exert greater influence in lowering the freezing point, decreasing the viscosity, and affecting textures, than do constituents of high molecular weight" (Bastin, E. S., op. cit., p. 31).

‖ See Harker, A., op. cit., p. 295. Among the catalyzers, especial importance is attributed, by Bastin (op. cit., pp. 30–31), to the influence of water gas and of hydrogen in helping the crystallization of pegmatite. These substances largely escape as the magma cools.

Let us consider, by way of illustration, an ideally regular mass of granitic magma which has been injected into a relatively cool rock formation. We may take it for granted that such an intrusion cannot lose heat uniformly throughout its volume. The marginal regions must cool more rapidly than the interior. Hence, *ceteris paribus*, the processes of cooling and of consolidation must progress inward from the contact with the country rock. In other words, these processes must be centripetal.*

Until the magma has quite hardened as a granite, there must be a constantly diminishing residuum which, as appears from the study of many examples, is known to have a tendency to increase in acidity. Since the mineralizers do not, except to a slight degree, enter into the reactions which they assist, their relative quantity in the diminishing remainder of the freezing magma must necessarily grow. Thus we have a liquid residuum in which the proportion of acid constituents and of catalyzers is steadily increasing.†

Without the catalytic agents such minerals as albite, orthoclase, and quartz would be so viscous that they could not crystallize. With these agents present, however, the molecular mobility of the remaining acid minerals is so augmented that crystallization is not only possible, but is even assisted to such a degree that the resulting crystals may be much larger than the average grain of the main body of the rock. In this way *pegmatite* may originate as a late product in the consolidation of the magma.‡

In the ideal case, then, according to this explanation, we might expect to find a mass of pegmatite in the heart of the intrusive body. If the tension due to cooling had developed joints, dikes of pegmatite might extend out as apophyses from the inner pegmatite segregation into the normal granite. The first type would have blended contacts; theoretically, the second type might possess sharp contacts where the granite had already hardened, at some distance from the central segregation. When derived in this way, pegmatites may be called *residual.*

Here it is necessary to observe that an intrusive body of ideal regularity of shape, such as we have been considering, is not natural. The great granite masses, being usually of the batholithic variety, are highly irregular. Moreover, they are

* Compare Crosby, W. O., and Fuller, M. L., The Origin of Pegmatites, Tech. Quart., ix, p. 325, 1896, p. 351.

† See, for example, Van Hise, C. R., op. cit., p. 728.

‡ The pegmatite mass found in the Quincy quarry, Mass., and recently described by Warren and Palache, is probably of this type. (Warren, C.H., and Palache, C., The Pegmatites of the Riebeckite-Ægirite Granite of Quincy, Mass., U. S. A., Proc. Am. Acad., xlvii, 125, 1911, p. 146.)

peculiar to the deeper parts of mountain ranges,* and, such being the case, often cut a country rock which has been rendered schistose by dynamic action consequent upon folding. On this account, actual field data show, not the hypothetical pegmatite core with its apophyses, but, instead, scattered here and there in the granite, numerous, relatively small, shapeless or elongate segregations having blended contacts. Dikes with sharply defined edges are less common. The small segregations of pegmatite, representing separate loci of the final operation of the concentrated mineralizers, indicate that, within layers parallel to the general external surface of the mass, consolidation is far from uniform. No doubt this is due in part to the unevenness of the contact.

Very often a *marginal* pegmatite zone may be observed between the main granite (or other plutonic) body and the country rock. From such a marginal zone dikes of pegmatite radiate outward. If the country rock is bedded or schistose, they follow its structural planes. Contacts of this marginal phase, both with the granite and with the country rock, are often blended, but they become more distinct away from the granite. Similar zones surround xenoliths.

The marginal pegmatite with its offshoots into the country rock is obviously a contact effect and cannot be a late phase in the centripetal consolidation of the granite body. Crosby, recognizing this discrimination, attributed it to the capacity of the magma, at high temperature, to absorb water from the country rock, this water later functioning as the main catalytic agent in the ultimate crystallization of the marginal pegmatite.†

According to this theory, a wedge of magma, in its forward advance into the country rock, would imbibe more and more water, and would have its fluidity augmented. Consequently, its penetrative efficiency and its tendency to freeze with pegmatite texture would increase. Loss of heat or lack of supply would bring the process to an end. Crystallization, if commencing after the cessation of injection, would proceed from the walls inward, and the first formed minerals would be more basic than the last. Thus the dike would acquire an acid

* Daly speaks of granites as being primarily mountain rocks (Daly, R. A., Abyssal Igneous Injection. . . . . This Journal (4), xxii, p. 196, 1906, p. 214–215. See also Geikie, A., Text-book of Geology, 4th ed., London. 1903, p. 724.

† Crosby, W. O., and Fuller, M. L., loc. cit., pp. 348–352. Van Hise writes: . . . "In many and perhaps most cases the water in the outlying pegmatite dikes and veins . . . . . has been largely derived from the surrounding rocks." (Van Hise, C. R., A Treatise on Metamorphism, U. S. G. S., Monog. xlvii, 1904, p. 728.) On the other hand, Geikie (op. cit., p. 768) and Harker (op. cit., p. 303), referring to the investigations of others, state that hot intrusions expel volatile substances from the country rock.

central region.* If, on the other hand, crystallization were initiated before the cessation of injection, the advancing magma might grow more acid by selective formation of the more basic constituents along the walls. In this manner, a dike, composed of quartz, feldspar, etc., might consist of quartz only at its outer end.

We may add further that in pegmatites or quartz veins of which the crystallization has been thus controlled by extraneous water, the relative amount of such minerals as topaz, tourmaline, and fluorite, should be small.

As for the metamorphic effects ascribed to pegmatites, the investigations of many geologists have demonstrated that granite intrusions have often, although not always, produced considerable exomorphic alteration.† The changes are due partly to heat and partly to the action of escaping volatile constituents.‡ The effects include induration, recrystallization, lit-par-lit injection, and metasomatism. At a distance, recrystallization in impure clastics may be evidenced by the presence of rutile needles; nearer the intrusive, by the occurrence of 'knots' and the micas; and still nearer, by such minerals as feldspar, andalusite, garnet, and amphibole, and by the aggregation of siliceous matter into large irregular quartz grains.

Concerning the relative importance of heat and volatile constituents in producing contact metamorphism, Geikie writes, "It would appear that mere dry heat produces only a small amount of chemical alteration." Also, ... "the presence of pneumatolytic agents . . . . has been largely influential, combined, doubtless, with great pressure, high temperature, and a continuance of these conditions for vast periods of time."§ The French school lays much stress upon the importance of metasomatic processes due to the action of gases.‖ Harker

* This type of distribution of the constituents, according to which the more basic minerals are marginal and the more acid ones are central, has been described by Smith and Calkins (Smith, G. O., and Calkins, F. C., A Geological Reconnaissance across the Cascade Range near the 40th Parallel. U. S. G. S., Bull. 235, 1904, p. 76), H. H. Reusch (Die Fossilien Fuhrenden Krystallinischen Schiefer von Bergen in Norwegen. German trans. by R. Baldauf, Leipzig, 1883), and many others. But Watson notes dikes in which quartz and feldspar are marginal, and mica, tourmaline, and garnet are concentrated in the middle zone (Watson, T. L., On the Occurrence of Aplite. Pegmatite, and Tourmaline Bunches in the Stone Mountain Granite of Georgia, Jour. Geol., x, p. 186, 1902).

† Geikie, A., op. cit., pp. 726, 778 et seq.

‡ G. W. Hawes notes the addition of boric acid (this Journal, xxi, p. 21, 1881). Certain volatile components, such as water gas and carbon dioxide, may be driven out of minerals in the country rock by the heat and may then play an active part in the metamorphism. (Van Hise, C. R., op. cit., p. 718).

§ Geikie, A., op. cit., p. 767.

‖ See Harker, A. (op. cit., p. 305), for a summary of the French views, and for several references. Michel-Lévy and Lacroix are noted.

contrasts the more intense thermal effects occasioned by basic intrusives, which contain few or no mineralizers, with the less intense effects of granites and other acid rocks.* He regards pneumatolytic metamorphism, however, as limited to a rather narrow zone next the contact.†

It is probable that the temperature of the magma at the time of its injection is not excessively high. This is indicated in the country rock by the absence of proof of true fusion along the contacts and by the abundance of minerals which developed during the metamorphism and which can crystallize only at relatively low temperatures—considerably below their freezing-points. Such are the micas, the amphiboles, the alkali-feldspars, quartz, tourmaline, and many others.‡ Since these minerals are also among the more important constituents of the granite itself, they prove a comparatively low temperature of consolidation for the magma.§

The ragged edges of inclusions (xenoliths), and, adjacent to the country rock, the coarseness of texture of the intrusions, do not of necessity prove a very high temperature for the latter. Magmatic solution (not fusion)‖ may account for this feature in the inclusions, and moderate warmth will explain the coarse texture.

The granite phase: Description.—Coming now to the description of the Acid Intrusive Series, we find that the Boston Neck granite occurs at various places along the western coast of Narragansett Bay from Watson's Pier (between locs. 11 and 12, C : 15, fig. 1) southward, and inland on Little Neck (B : 16, fig. 1), Boston Neck, and Tower Hill (A and B : 14 and 15).

This rock is typically of medium grain ; is white, pinkish, or cream-colored ; and consists predominantly of microcline, with quartz, micropegmatite, microperthite, a coarsely twinned plagioclase, and orthoclase. A little biotite or muscovite may be present, and apatite, zircon, magnetite, rutile, and garnet, are among the less common constituents. Megascopically, a varying degree of schistosity is seen. Under the microscope, the quartz appears somewhat strained, the feldspar grains may be cracked or faulted, and the micas are more or less bent.

* Harker, A., op. cit., p. 189.
† Ibid., p. 304.
‡ Ibid., pp. 187, 284.
§ Harker (op. cit., p. 186) quotes Lehmann's estimate of 500° as "probably by no means too low." Referring to Sorby's investigations on the vacuoles of crystals, he shows that the results obtained by Sorby lead to the same conclusion (pp. 187–189). See also Geikie, A., op. cit., pp. 412–413. E. S. Bastin (op. cit., pp. 38–39), applying the data of Wright and Larsen, arrives at the conclusion that pegmatites crystallize not far below, nor far above, 575°C. (See Wright, E. F., and Larsen, E. S., Quartz as a Geologic Thermometer, this Journal, iv, 28. 1909.)
‖ Geikie, A., op. cit., pp. 767, 776.

FIG. 1.

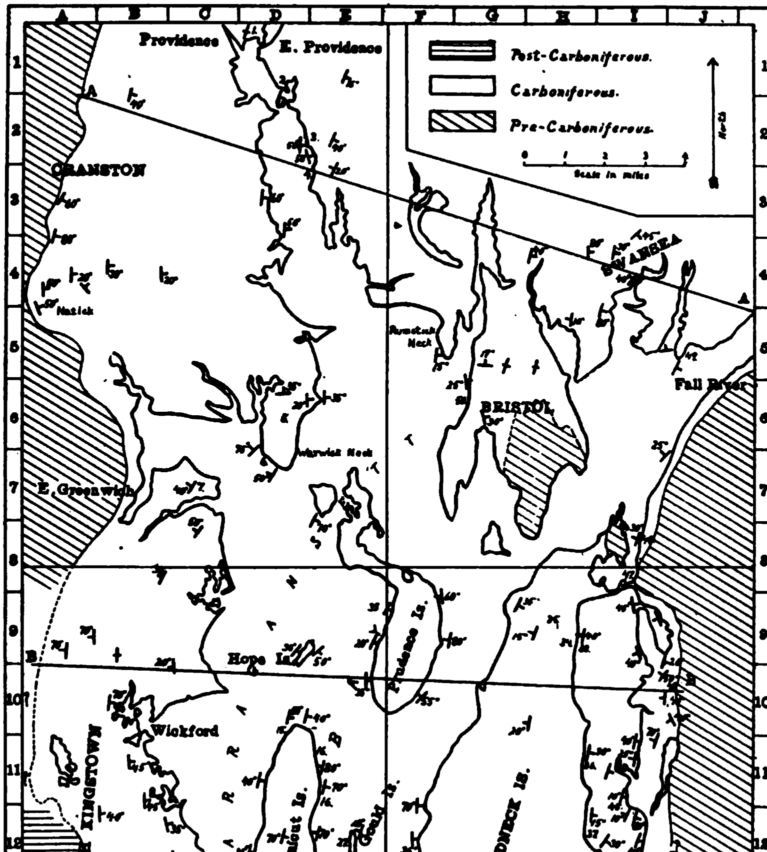


FIG. 1. Outline map of the southern half of the Narragansett Basin.

—Relations of the granite phase to the Carboniferous sediments.—Within the Boston Neck granite are many elongate, highly metamorphosed inclusions of schist, which, as inferred from their structural and petrologic relations, are undoubtedly parts of the Carboniferous formation of the Basin.* The dimensions of these xenoliths vary from an inch to several scores of feet. In general, their lengths trend nearly north-south, i. e., about parallel to the strikes of the bedding of the adjacent Carboniferous strata, and their schistosity runs in the same direction. Their extremities are often ragged, and sometimes strips may be observed to have been torn away and removed a short distance before having been frozen in. Apophyses project into them from the granite.

At the contact there is more or less blending, due either to solution or to interpenetration by the magma at the time of injection. Near the more basic xenoliths the granite may display an increase in its content of biotite and garnet. Microscopic sections show that grains of the feldspars which are characteristic of the intrusive may occur in the inclusion, abundant near the contact, but decreasing in amount away from it. While the granite never becomes aphanitic adjacent to the country rock, it may grow sensibly finer. Apparently the schists were comparatively warm when intrusion took place.

There can be no doubt, therefore, that the Boston Neck granite is irruptive into, and consequently later than, the Carboniferous strata.

The pegmatite phase: Description.—Pegmatite is found, not only at various localities in the granite area, but also nearly as far northward as Hamilton (Loc. 8, B–C : 11, fig. 1), and eastward, in the form of small dikelets, on Dutch Island (Loc. 14, C–D : 13).

These pegmatites are composed chiefly of microcline, microperthite, graphic granite, and quartz, a little orthoclase, acid plagioclase, and muscovite. Biotite may be present instead of, or accompanying, the muscovite. Garnet may be plentiful. 'Pneumatolytic minerals,' such as beryl, tourmaline, topaz, and fluorite, are very rare. Tourmaline alone has been found in one instance by the writer. Kemp stated that, westward, tourmaline, monazite, and molybdenite have been observed.† Of the principal constituents, the feldspars occurs in crystals, often excellently shaped, up to thirty inches in length. Quartz grains, too, may measure as much as two or three feet across. Muscovite occurs either as thick plates, sometimes two inches

* Shaler, N. S., Foerste, A. F.. and Woodworth, J. B., Geology of the Narragansett Basin, U. S. G. S., Monog. xxxiii, 1899, pp. 245, 377.

† Kemp, J. F., Granites of Southern Rhode Island and Connecticut. Bull. Geol. Soc. Am., x, p. 361, 1899.

wide, or in the form of radiating aggregates known as 'plumose mica.' The garnets seldom attain dimensions greater than ¼ inch.

—*Relations between the pegmatite phase and the granite phase.*—From the foregoing remarks it is evident that the composition of the pegmatite closely resembles that of the Boston Neck granite—so closely, indeed, that if for no other reason, we should be inclined to regard both as genetically akin. There are other grounds, however, for this assumption. In the first place, pegmatite may traverse the granite in the form of dikes or as regular patches and streaks. Especially in the latter case, the two rocks grade into one another so insensibly that no boundary can be set between them. These pegmatite bodies would seem to be of the residual type, as described above. In the second place, the granite sometimes becomes pegmatitic toward the Carboniferous schists, so that its contact zones, instead of being finer in texture, may be coarser than its normal phase, and its apophyses into the schists may be, and in fact generally are, pegmatitic. This is marginal pegmatite. Along the coast south of Watson's Pier, granite and pegmatite may be seen thus intimately associated with blended contacts, the effect often being that of schlieren on a large scale. Southward, the pegmatite phase becomes less important; northward, the granite phase becomes less important. The last evidences of the granite are seen in narrow streaks in a large pegmatite dike on the Bonnet (small projection of western coast in C:14, fig. 1).

—*Relations of the pegmatite phase to the Carboniferous sediments.*—Those pegmatite dikes which cut the Carboniferous formation may be many feet or less than an inch in thickness. On Boston Neck they are very numerous and very large, and the schists occupy relatively little space. Exposures on the Bonnet, for instance, are chiefly of the schists which, however, are intersected by five or six large dikes and many little ones. Still farther north, on Barber's Height (Loc. 9, B: 12), pegmatite is rarely encountered.

Great thickness does not necessarily imply great length; for intrusives twenty or thirty feet across may thin out and come to an end (at the topographic level) within a space of twenty-five feet. On the other hand, apophyses from the larger dikes may run with nearly a uniform width of only five or six inches for distances of several scores of feet; but they commonly end by tapering to a point within a few yards of their parent body. Sometimes the thickness may alternately increase and decrease, even to such a degree that an intrusion appears in cross-section as a succession of short, discontinuous,

lens-shaped masses.* (See fig. 2.) Some of the dikes are straight; others have elbow-bends; and still others appear to be highly contorted (see figs. 2–12).

As regards contact phenomena, the margins of these dikes, although ordinarily pretty sharply defined, may display bending in a narrow zone. The edges are often jagged or otherwise irregular, in a way to suggest that the schists were torn, and not broken, at the time of irruption. Elongate, bent, shredded inclusions, as frequent here as in the granite, generally trend parallel to the walls. Within the smaller dikes, not more than a few inches in thickness, the central zone may consist of nearly pure quartz, or of quartz and muscovite, and the feldspars with a little quartz and muscovite are then limited to the marginal portions. Biotite and garnet were also observed to occur more particularly near the contact.

Fig. 2.

Fig. 3.

Fig. 4.

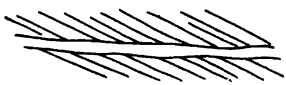


Fig. 2. Lenses of pegmatite in schist. (Seen on the Bonnet.)
Fig. 3. Dikes of coarse granite cutting schist. (Tower Hill.)
Fig. 4. Dike, largely of quartz with a little feldspar, cutting across schistosity. (The Bonnet.)

Many of these apophyses show a progressive increase in acidity away from their point of origin, and this modification may go so far that they are composed of quartz only near their tapering extremities. In other words, the pegmatite dikes may grade into quartz veins.

The country rock may exhibit evidences of exomorphic alteration in the recrystallization of its constituents, in the formation of knot-like bunches of quartz up to one-half an inch across, or in the introduction of such minerals as feldspar and especially muscovite and sericite.† It may possess a characteristic greasy lustre consequent upon such changes.

* Similar successions of lenticular masses are described by E. S. Bastin. (Quartz and Feldspar Deposits of Maine, U. S. G. S., Bull. 315, p. 383; 1906, p. 384.)

† Sericite is no doubt the result of dynamic metamorphism, an effect of the intrusion of the pegmatites.

As we have explained in Part I, the strikes of the beds in the southwestern portion of the Basin are nearly north-south and the dips are commonly steep eastward (fig. 1). The attitude of the schistosity is usually similar. These structures (either or both) had a general directional influence upon the intrusives, and this influence was more efficient southward. Thus, in the Watson's Pier district, the dikes, which are prevailingly of large size, usually trend along north-south lines. On the other hand, in the Bonnet exposures,* large dikes are

Fig. 5.

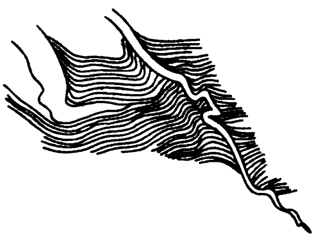


Fig. 6.

Fig. 5. Pegmatite dikes in schist. Note the distortion of the schistosity against the dikes. (Southern end of Boston Neck.)

Fig. 6. Pegmatite dike cutting Carboniferous schist and having inclusions of the same. (Figs. 6 to 12 are of features seen on the Bonnet.)

few and, when present, may cut the strata obliquely or may bend sharply from a nearly north-south course and, crossing the beds nearly perpendicular to the strikes, disappear under the waters of the Bay or landward beneath the soil.

Small dikes and apophyses are more numerous on the Bonnet than on Boston Neck. In the former place many of them show absolutely no dependence upon structures in the country rock. A few have been seen to extend into joints of an east-west set. When they are approximately or quite parallel to the cleavage, they may be relatively long and narrow and of pretty uniform thickness (fig. 4); where they cross the cleavage, they are shorter, thicker, bunchy or highly irregular in shape, or are convoluted (see figs. 5–11). Yet that this is not always true is proved by the straightness of such stringers as the middle third of the small apophysis on the left in fig. 11. Sometimes pinching seems to have brought about a separation of the dike (fig. 10). In this case, however, it should be noted that the two ends do not lie in the same cleavage plane. In spite

* The strata of the Bonnet have a well developed cleavage which strikes a little east of north and has an average dip of 60° E. Differences of texture, where visible in these rocks, prove that the bedding has a like attitude.

of these suggestions of folding and squeezing, the lithological structure and the texture of the pegmatite display little, if any, evidence of crushing.

Fig. 7.

Fig. 8.

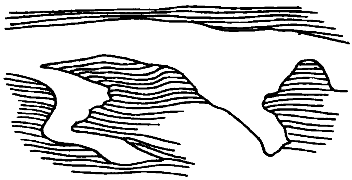


Fig. 7. Tortuous dike of pegmatite cutting the schistosity, yet with a tendency to trend parallel to this structure.
Fig. 8. Thick pegmatite dike, which, although irregular, shows a tendency to trend parallel to the schistosity of the country rock.

Fig. 9.

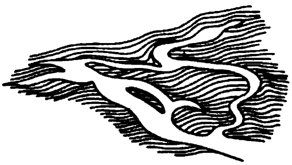


Fig. 10.

Fig. 9. Pegmatite dike with a loop-like lateral extension which encloses a large xenolith of the country rock.
Fig. 10. Pegmatite dike, showing relations between the schistosity and the edges of the dike.

Fig. 11.

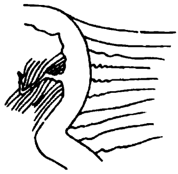


Fig. 12.

Fig. 11. Crumpling of schistosity against dike of pegmatite.
Fig. 12. Irregular dike of pegmatite, bedding (parallel to the upper lines in the diagram), and cleavage (parallel to the lower lines in the diagram).

Absolute parallelism of the intrusive and the foliation of the country rock are very rare. When the cleavage is intersected at an acute angle, it may be nearly coincident with the sinuosities of the contact (fig. 10). When it distinctly abuts against the dike, it may be minutely crumped or may fan out (figs. 10 and 11).

Immediately above the dikes depicted in figs. 10 and 12, the stratification, which was perfectly clear in the junction of a fine dark schist and a coarse light schist, had its dip and strike about parallel to the average attitude of the schistosity. Careful search was made for bedding where crumpling might occur, but with little success. In only one instance there were very obscure traces of close folding. Yet the very fact that the cleavage is contorted proves that the pre-existing stratification must also have suffered deformation of like nature.

The quartz vein phase: Description.—Large and small veins of quartz are found throughout the southern half of the Narragansett Basin. They are more abundant southward and westward.

The quartz of these veins is milky or creamy in color. Feldspar has been found in small quantity, generally near the margins of the veins, as far north as the Devil's-Foot Ledge (in B : 9, where vertical dip is shown, fig. 1), near East Greenwich, and, eastward, on Dutch and Conanicut islands. Locally, a little chlorite, muscovite, sericite, pyrite, etc., have been discovered.

Miarolitic cavities are occasionally seen (East Providence area and Sachuest Neck), and, in these, crystal terminations may be well developed; but, as a rule, the quartz is massive. Comb-structure was not recorded.

—*Relations between the quartz vein phase and the pegmatite phase.*—We have explained above that pegmatite apophyses may become wholly quartzose at their extremities. We now see that the quartz veins may contain some feldspar. Every gradation between typical pegmatite dikes and pure quartz veins may be observed in this region. On the Bonnet, where all the varieties are best illustrated, quartz veins sometimes cut the pegmatite. Hence we infer that the quartz veins are genetically allied to the pegmatites and represent the extreme acid phase of the Acid Intrusive Series.*

—*Relations of the quartz vein phase to the Carboniferous sediments.*—Those veins which cut the Carboniferous sediments are of every variety of shape and size. Usually they are

* The same relation between quartz veins and pegmatite dikes has been recorded in other regions by I. H. Ogilvie (Geology of the Paradox Lake Quadrangle, N. Y., N. Y. State Mus. Bull. 96, 1905), xx; Van Hise (op. cit., p. 724); T. T. Read (Nodular-Bearing Schists near Pearl, Col., Jour. Geol., xi, p. 493. 1903); J. F. Kemp (The Rôle of the Igneous Rocks in the Formation of Veins, Am. Inst. Min. Eng., Trans. xxxi, p. 169, 1902); Crosby and Fuller (op. cit., pp. 329, 334); G. H. Williams (General Relations of the Granitic Rocks in the Middle Atlantic Piedmont Plateau, U. S. G. S., Ann. Rept. xv, p. 657, 1894); C. R. Van Hise (Principles of North American Pre-Cambrian Geology, U. S. G. S., Ann. Rept. xvi, Pt. I, p. 581, 1895, p. 688); and many others.

not sheet-like, but tend rather to occur as large, irregular masses or bunches, from which short and long stringers run out in all directions. The shapeless type is particularly characteristic of those veins which are in the pelitic and graphitic rocks, while the sheet forms are found chiefly in the psammites and psephites, where they occupy joint-fissures. It is important to note not only that a great majority of these veins are in rocks of fine texture, but also that they are especially abundant where the country rock is much contorted. Localities where quartz veins are numerous and where contortion in the schists is at a maximum are as follows: southern end of Warwick Neck (D:7); part of the coast of Bristol Neck, northwest of Bristol (G:5–6); Brayton Point (Loc. 49, J:5); several places along the eastern coast of Aquidneck Island; along the eastern shore of the Sakonnet River, north of Brown Point (Loc. 44, I:12); Sachuest Neck; Gould Island (E:12); numerous points on the eastern coast of northern Conanicut Island; on Freebody's Hill (between Locs. 17 and 19, D:13) and on the Beaver Tail Peninsula (Loc. 23, D:14 and 15), Conanicut Island; Dutch Island (Loc. 14, C–D:13); and at points along the western coast of the Bay. Whether introduction of the veins was consequent upon the intense folding, or vice versa, is a question to be discussed later.

As with the pegmatite apophyses on the Bonnet, the statement holds here also that veins which cross the schistosity are generally thicker and more contorted than those which run nearly parallel to it. Except in this way, the veins exhibit very little dependence upon directional structures of the country rock.

The edges of the veins, always sharply outlined, are ordinarily uneven or jagged. Horses of the country rock are not infrequent. Exomorphic change is seen in an excess of sericite, oriented parallel to the contact as if caused by pressure concentrated near the vein.

The presence of feldspar along the margins, as already described for certain cases, might be attributed to the action of the injected material upon a country rock containing the elements of this feldspar; but the fact that the relative proportion of this mineral (1) does not vary sympathetically with differences in the composition of the surrounding rock, and (2), when studied at different localities and compared, reveals a general and uniform increase in a southwesterly direction, toward the pegmatites and the granite, discountenances such an assumption.

Summary.—We may now summarize the points brought out in describing the Acid Intrusive Series, at the same time applying the facts noted under the theoretical considerations.

(1). The Boston Neck granite is genetically related to the pegmatites, for (a) both contain essentially the same minerals; (b) both phases may alternate, schlieren-like, in the same dike; and (c) the granite may be seen to grade into the pegmatite.

(2). The pegmatites and the quartz veins are genetically related, for the pegmatites, by constant increase in their relative content of quartz and decrease in their relative content of feldspar and other minerals, grade into true quartz veins.

(3). The Acid Intrusive Series (Boston Neck granite, pegmatites, and quartz veins) is intrusive into the Carboniferous sediments of the Basin, for (a) it cuts the sediments in dike form; (b) it contains inclusions of the sediments; (c) it shows endomorphic effects in contact with the sediments; and (d) the sediments display exomorphic alteration near the intrusive rocks.

(4). Of the several members of the Acid Intrusive Series, (a) the residual pegmatite represents a somewhat later stage of crystallization than the main body of the granite; (b) the marginal pegmatite probably crystallized about the same time as the contact portions of the granite body; (c) the offshoots from the marginal pegmatite zone, and the quartz veins, represent a later stage of crystallization than do the marginal pegmatites proper.

Hence, the younger members of the series are more acid than the older members.

(5). The Acid Intrusive Series is distributed as follows: (a) the granite occurs only southwest and west of the southwestern part of the Narragansett Basin, as a border rock; here, too, are the residual pegmatites; (b) the marginal pegmatite and its offshoots occur chiefly in the southwestern portion of the Basin, and have somewhat greater extent than the granite, northward, northeastward, and eastward; (c) the quartz veins occur locally in all parts of the southern half of the Basin, but more abundantly southwestward toward the pegmatites.*

Hence, the series exhibits higher acidity and evidence of more intense operation of mineralizers, with increasing distance from the granite.

(6). The most important catalytic agent active in the crystallization of these intrusive rocks appears to have been water gas, for there are found very few of the rarer 'pneumatolytic minerals,' the occurrence of which would be a token of the presence of other volatile constituents.

(7). Evidences for solution and chemical alteration as contact phenomena—slight in any case†—are most pronounced near

* Such distribution may not be due to horizontal distance from a vertical, or nearly vertical, contact, for the upper surface of the granite may slope northward and eastward.

† It is therefore questionable whether solution has contributed much toward opening the spaces for these bodies, as was suggested by Crosby and Fuller for similar dikes and veins (op. cit., p. 338).

the granite, less so near the pegmatites, and least near the quartz veins.

(8). While the quartz veins are not dynamically metamorphosed, and the pegmatites have suffered at most only slight crushing, the granite, which represents the oldest phase of the series, locally has prominent gneissic structure.

—*Relations of the intrusion of the acid intrusives to the folding, metamorphism, and schistosity of the Carboniferous sediments.*—We have said (p. 456) that, while the granite may grow finer adjacent to the country rock, it never becomes aphanitic. Indeed, in some places it shows no diminution of texture. There is no marked sign of chilling. Instead, the phenomena indicate that the country rock was relatively warm at the time of intrusion.

The marginal zones of the pegmatite dikes are frequently of finer grain than the central regions. This might be explained partly or largely by the influence of the inwardly assembling mineralizers, and, to a less degree, by that of surrounding temperature conditions. Nevertheless, here again, nothing suggests a cool country rock.

Because of the massive nature of the quartz veins, it is impossible to ascertain their relations to the sediments in this particular.

We conclude that the temperature of the country rock, at the time of intrusion, was high.

Exomorphic alteration, due to injection of the Acid Intrusive Series, includes solution, introduction of minerals peculiar to the intrusive, and recrystallization of original constituents of the country rock. These changes are such as to imply the coöperation of considerable heat and pressure, of solvent power, of the action of mineralizing agents, and of long time. They are characteristic and are distinct from the results of dynamic metamorphism, as described in Part II for the entire area investigated, in spite of the fact that this metamorphism is more severe westward and southward. The zone of contact metamorphism is limited to but a few feet in breadth. We must infer that the Acid Intrusive Series, although responsible for some contact metamorphism, did not cause the widespread metamorphism of the basin.

We noticed that the Acid Intrusive Series exhibits a dependence upon certain directional structures (stratification and schistosity) in the country rock, and that this dependence increases southward. It follows from the distribution of the series that the degree of dependence of the different members varies inversely as their degree of acidity. And it follows, further, that this degree of dependence is less in the younger intrusives; for the more acid members, representing an advanced stage of differentiation, are somewhat later in origin.

Again, we have shown that, in the Bonnet-Boston Neck region, stratification appears to coincide with the planes of schistosity. The Carboniferous rocks of this district are of comparatively uniform texture. Conglomerate schists are fine-grained and are rare, and very fine pelitic schists are not common. The bulk of the sediments are sandstone schists which range from coarse to fine. We might conclude, then, that the stratification, *per se*, would not have afforded easy access to an intrusion—certainly by no means as easy as if the sedimentary series consisted of rapidly alternating textures.

On the other hand, since schistosity is well developed, it would seem to have offered relatively little resistance to the injection of magma along its planes.

These facts being admitted, we may assume provisionally that those dikes which trend parallel to the schistosity and bedding were guided more efficiently by the schistosity than by the bedding.

Northward and eastward the quartz veins are best developed in pelitic and coaly rocks, that is, in rocks of fine grain. In a large sense, then, these veins may be said to be related to the stratification; but they occur in huge masses which cut promiscuously across the finer laminæ of bedding and cleavage alike, and are, therefore, not immediately dependent upon either structure.

The intimate relations between the pegmatite dikes and the schistosity of the Carboniferous sediments were described above (p. 457 et seq.). Among the features there mentioned, the conspicuous lack of dependence of the intrusions upon the direction of the schistosity, their occurrence sometimes in series of lenticular bunches or in irregular masses, which seem to have been squeezed apart, and their frequently tortuous shape, are strongly suggestive of their having been injected before the period of deformation and metamorphism, and of their having been subsequently folded together with the sediments. But against this supposition, the following objections may be raised: (1) The internal structure of the dikes reveals little or no crushing. (2) Inclusions have schistosity which is practically identical with that of the country rock in respect to degree, nature, and direction. (3) Loops of pegmatite, which surround such inclusions, prove that all curves of these dikes could not have been parallel to the bedding. (4) In many cases the loops are of a type difficult to explain if injection preceded folding. (4) In the midst of an area containing numerous, often highly tortuous dikes, perfectly or nearly straight apophyses sometimes extend for considerable distances. (6) The method in which the cleavage abuts against the dikes, either by fanning out (fig. 12) or with minute local crumpling

(fig. 11), is suggestive, not of interference by the dikes, as if already present, but of pressure exerted against the cleavage by the force of the incoming intrusive.* (7) Except in one doubtful instance, the stratification, wherever discernible, is regular and not contorted. We admit, however, that, where the cleavage is crumpled, the bedding laminæ also must have suffered some minor deformation; but there are faint indications that both cleavage and stratification, when folded as well as when relatively plane, are approximately coincident.

From these statements we infer that the intrusion of the dikes—at least of those on the Bonnet—was chiefly subsequent to the deformation of the enclosing Carboniferous sediments.

Conclusions to the study of the acid intrusives.—In regard to the Acid Intrusive Series, we conclude: (1) that, since endomorphic and exomorphic metamorphism are slight, the intrusion was weak; (2) that, since the granite sometimes has a conspicuous gneissic structure, it was injected while the forces that caused the folding of the country rock were still active; (3) that, since the pegmatite shows at most only slight crushing, its dikes entered in general toward the close of the period of deformation; (4) that, since the quartz veins are not dynamically metamorphosed, they were injected after deformation was at an end; (5) that, since injection of the Acid Intrusive Series, initiated during the process of folding, was not completed until after the close of this process, and, since the quartz veins are a differentiation product of the pegmatites, while the pegmatites, in their turn, are a differentiation product of the granite, therefore, the period of intrusion must have been of long duration;† (6) that, since the processes of

* Compare Bastin, speaking of the Maine pegmatites: "The bending of the schist folia in the manner shown indicates also that the pegmatite when intruded behaved to a certain extent like a solid body capable of exerting differential thrust on the inclosing walls of schist." (Bastin, E. S., Geology of the Pegmatites and Associated Rocks of Maine, U. S. G. S., Bull. 445, 1911, p. 34.)

† Accurate statements of the relative ages of folding, intrusion of acid rocks, and production of metamorphism in regions where these phenomena occur, are rare in the geological literature. The following may be mentioned: G. O. Smith and F. C. Calkins described schists cut by granodiorite and by pegmatites which were somewhat gneissic. (A Geological Reconnaissance across the Cascade Range near the 40th Parallel, U. S. G. S., Bull. 235, 1904.) E. S. Bastin held that the schist of Boothbay Harbor, Maine, has been intruded by granite and related pegmatite later than deformation and metamorphism. (Quartz and Feldspar Deposits of Maine, U. S. G. S., Bull. 315, 1906, p. 384.) From studies in various localities, W. O. Crosby wrote, "In every instance the pegmatite is clearly younger than the foliation of the enclosing rocks." (Crosby and Fuller, op. cit., p. 339.) R. A. Daly mentioned phyllites cut by quartz veins which seemed to have shared in the crushing, but most of which were later. (The Geology of Ascutney Mountain, Vt., U. S. G. S., Bull. 209, 1903, p. 15.) In his 'Granites of Maine (U. S. G. S., Bull. 313, 1907), T. N. Dale said of the Waldoboro quarry, "The granite sends small apophyses into the schist and also contains inclu-

intrusion and of deformation were in part contemporaneous, the forces active in the folding may have assisted in determining the shapes and directions of the dikes;* and, (7) that, not being the cause of the regional metamorphism of the Basin,† and, moreover, having its inception during deformation, the process of intrusion may have been a consequence of the action of the deforming forces.

RELATIONS BETWEEN THE MINETTE DIKES AND THE ACID INTRUSIVES.—Because the minette dikes and the Boston Neck granite entered the Carboniferous strata during the period of deformation, there is strong reason to suppose that they may be related to one another. Someone has suggested that the pegmatites and quartz veins, on the one hand, and the minettes, on the other hand, represent complementary poles of differentiation. Advocates of this view would have to explain (1) why the minettes are so often intersected by quartz veins which are almost certainly of the Acid Intrusive Series; (2) why there are so few minette dikes as compared with the vast number of pegmatite dikes and quartz veins; and (3) why

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sions of it. The granite was erupted (sic) after or during the folding of the schist, otherwise it would have become a gneiss" (p. 51). We find in Geikie's 'Text-Book' that the granites of southeastern Ireland were injected into Lower Silurian rocks after the latter were folded (p. 726). Finally, we may quote from T. A. Jagger and E. Howe (The Laccoliths of the Black Hills, U. S. G. S., Ann. Rept. 21, Pt. III, 1901): "Throughout the Rocky Mountains igneous phenomena have accompanied colossal movements of uplift, folding, and faulting" (p. 187). "The history of intrusion in the Black Hills is believed to be intimately associated with the history of the larger deformation. Intrusion is not conceived to have been in any sense a cause of the greater uplift, but an effect" (p. 282). "Cross recognized in the Mosquito Range and Tenmile district the influence of orographic movements concomitant with intrusion" (p. 286). "In many places (in the Rocky Mountains) intrusions accompanied or followed the greater movements. . . " (p. 287).

* Compare A. Harker: . . . . "When very large bodies of magma are intruded under a considerable cover, their form and disposition may be determined mainly by the distribution of stress which thus finds relief, with very little regard to the structure of the encasing rocks" (Natural History of Igneous Rocks, N. Y., 1909, p. 83).

† G. F. Loughlin wrote: "The details of metamorphism in the Kingstown area have not been exhaustively studied, but it is very evident, from the field work done, that vertical dips and the most complete recrystallization of the sediments are found where granitic intrusions are most abundant. There seems, then, no reason for doubting that in the Kingstown area . . . . the granite intrusion accompanied metamorphism and folding. As the Kingstown sediments have been determined to be of Carboniferous age, the time of granite intrusion and folding may be correlated with the Appalachian Revolution." (Intrusive Granites and Associated Metamorphic Sediments in Southwestern R. I., this Journal, xxix, 447, 1910, p. 445.) The first statement seems to lead one to infer that the metamorphism of the sediments was largely due to intrusion; but, as we have attempted to explain, we regard the amount of metamorphism primarily caused by the intrusion to be slight in comparison with that due to folding and concomitant shearing, together with the static after-effects.

the minettes display evidences of much more shearing than is seen in the pegmatites and quartz veins. The number of the minette dikes is so small, and their importance in the present discussion is so slight, that they will not be considered further here.

Summary and Conclusions.

(1). The Narragansett Basin is a body of Carboniferous strata which (*a*) have been deformed according to the Appalachian type of folding; (*b*) have been regionally metamorphosed; and (*c*) have been intruded by igneous rocks.

(2). The Basin is surrounded on nearly all sides by a nearly continuous border of pre-Carboniferous rocks from which the Carboniferous sediments were derived. The border is interrupted by the post-Carboniferous intrusives, in South Kingstown, and by arms of the sea, between Narragansett Pier and Sakonnet Point.

(3). The Carboniferous strata represent sediments which (*a*) were heterogeneous in composition, containing varying amounts of feldspar, ilmenite, magnetite, carbonaceous matter, etc.; (*b*) were deposited by fresh water; and (*c*) were brought together and laid down by currents which had rather rapid variations in direction, rate, and carrying power.

(4). The folding of the strata in the southern half of the Basin was caused by forces which acted radially, but with much greater intensity along approximately east-west lines than along north-south lines.

(5). In different parts of the southern half of the Basin, the deformation effected by these forces shows variations in intensity—variations which owe their origin (*a*) to variations in the forces; (*b*) to vertical position in a given fold; or (*c*) to rock texture.

(6). The intensity of the deformation, that is, the degree of compression, as seen in the principal folds and in the minor folding and contortion, increased southward.

(7). The regional metamorphism is both dynamic and static.

(8). The effects of the dynamic regional metamorphism (*a*) are seen in all parts of the southern half of the Basin; (*b*) are not directly related to textural differences and to stratigraphic depth; (*c*) increase in intensity southward and westward.

(9). The schistosity of the Carboniferous sediments is often related, in respect to attitude, to the bedding.

(10). The effects of the static regional metamorphism are superposed upon the effects of the dynamic metamorphism and are a consequence of the continuation of anamorphic chemical changes after mechanical movement had ceased.

(11). The post-Carboniferous intrusives include a few minette dikes, on the one hand, and an extensive, perhaps related, series of granites, pegmatites, and quartz veins (Acid Intrusive Series), on the other hand.

(12). Of the Acid Intrusive Series, the granite (Boston Neck granite) is oldest, the pegmatites are younger, and the quartz veins represent the latest differentiation phase.

(13). The Boston Neck granite is limited to Boston and Little Necks, the Tower Hill ridge, and westward (Sterling granite); the pegmatites have a wider distribution (within the Basin), north to Barber's Height and east to Dutch Island; and the quartz veins, although most abundant in the southwestern portion of the Basin, occur throughout the area investigated.

(14). These igneous rocks (Acid Intrusive Series and probably minettes) were injected during, and immediately subsequent to, the folding of the Carboniferous sediments.

(15). More or less static and dynamic metamorphism attended the intrusion of these igneous rocks, but this metamorphism is local and is of a distinctly different character from the regional metamorphism due to the folding.

We conclude, then, that the Carboniferous strata of the Narragansett Basin, after deep burial, were folded by forces that acted with greater intensity in the south; that, contemporaneous with, and consequent upon, this deformation, these sediments were regionally metamorphosed; that this deformation and this metamorphism were accompanied, in their later stages, by the intrusion of certain igneous rocks—a process which continued, with magmatic differentiation, for some time after folding ceased; and that, these facts being accepted, the regional metamorphism, and the injection of the post-Carboniferous igneous rocks, may be regarded as nearly parallel effects of the mountain-building forces.

Cambridge, Mass.,
February 5, 1912.

Art. XXXIX.—*One Phase of Microseismic Motion*; by J. E. Burbank.

Seismologists generally include in the term microseismic motion all pulsations and movements of the earth's crust which are not attributable to earthquakes or to motion of a more or less violent and abrupt nature.

Microseisms may be due to local causes, as industrial operations and ordinary traffic, storms and waves on adjacent shores, frost action, and possibly by wind, tide, and waves on distant shores. The kind and number of microseisms recorded at any place will naturally be limited by the adjustment and damping of the pendulum and the nature of the record; as a photographic registering seismograph with high magnification will record microseisms when a mechanically registering seismograph would give only a smooth straight line. Moreover, with mechanical registration the recording surface may not always be uniformly coated with lampblack and hence will offer varying resistance to the lateral movement of the writing stylus. The mechanical registration with low magnification offers a distinct advantage in studying certain microseisms, since it does not give such a large mass of detail, in which it is often difficult to identify a particular type of motion.

At the Cheltenham Magnetic Observatory we have been studying the relation between microseismic motion and the variations in atmospheric pressure since 1906. Our seismograph is a two-component, 10 kilogram, horizontal pendulum, of the Omori type, with mechanical registration and magnification of ten times. The periods of the pendulums have been kept between 24 and 29 seconds. With the seismograph operating under these conditions, only the more pronounced microseisms are recorded, yet it is an interesting fact that during nearly five years record there have been not more than 25 cases of moderate barometric changes in connection with which microseisms might have been expected and were not found on the seismograph traces.

The microseisms accompanying atmospheric pressure variations have a remarkably regular wave-like motion which almost always shows a rhythmical increase and decrease of amplitude indicating interference. The waves occur in groups of from 6 to 12, and vary in amplitude with the intensity of the barometric variation. The most pronounced cases indicate a movement of the earth particles at this place amounting to about 0·05 millimeters on each side of their mean position.

The results of our observations from September 1, 1906, to

January 31, 1908, were published* in tabular form, with full notes on the atmospheric pressure conditions. These results showed that the most pronounced microseisms were almost invariably connected with the passage of deep lows across the coast line from land to sea, or vice versa. It was also pointed out that the water area under the pressure disturbance would be in hydrostatic equilibrium, while the land area would be subject to a stress which would be greatest at the shore line, hence we should expect the greatest microseismic motion when the center of a low area moves rapidly over the coast line.

This reasoning has been confirmed by approximately 100 well-defined cases during the past 5 years. In fact, during the period under investigation there has not been a single case of a well-defined low area which has crossed the coast line between Maine and Florida which has not been accompanied by well-defined microseisms. It was also noted in the above paper that a rapid rising or falling pressure over the coast was accompanied by microseisms.

This type of microseisms has been studied by Dr. Otto Klotz of Ottawa, Canada, who finds that the most marked cases at Ottawa are connected with the passage of low areas down the St. Lawrence and into the Gulf. He considers the microseisms due to difference in pressure, which is in agreement with our conclusions.

The movement of a low area down the St. Lawrence and into the Gulf should be regarded as a passage across the coast line, although Dr. Klotz makes the statement† that such passage is not marked by microseisms. This statement is not in agreement with our results at Cheltenham, which is peculiarly well located geographically for the study of such phenomena. Of 300 microseisms recorded here between September 1, 1906, and June 30, 1911, all but 32, about 10 per cent, have been definitely connected with some change of pressure occurring over the coast line between Labrador and Texas.

That a change of pressure over land areas alone, although of considerable intensity, does not produce appreciable tremors is borne out by the following observations; in many cases intense depressions have developed over the Mississippi valley and over the Lakes and have moved northward and eastward entirely unaccompanied by microseisms until they had approached sufficiently near the ocean to cause a steep pressure gradient over the coast. Another small group in which a low develops over the Gulf or the lower Mississippi valley and moves rapidly northeastward, passing out to sea over the middle Atlantic

* Journal Terrestrial Magnetism, vol. xiii. pp. 1–20, March, 1908.

† Department of the Interior, Canada, Report of Chief Astronomer, 1908, pp. 24–40.

states,—in such cases no appreciable microseisms occur until it approaches the coast, when they begin and reach their greatest intensity while the center is passing out to sea. Another very rare condition is when a low develops over the Gulf states and moves northeastward along the Allegheny mountains, passing into Canada without producing any great pressure changes along the coast line; in such cases no microseisms are recognizable. Still another very rare case is when a low develops over the ocean east of Florida and recurves northwestward, passing inland over the South Atlantic coast. The microseisms rapidly decrease after the center passes inland, although it may still be of considerable intensity.

Of the 268 microseisms recorded here during the last 5 years and which appear connected with atmospheric variations, approximately two-thirds occur in the period October to April, when pressure changes are more frequent and abrupt; they occur very rarely during June, July, and August, when pressure gradients are very small. During these winter months these microseisms often continue for several days, diminishing and increasing in intensity as a succession of abrupt pressure changes from low to high sweep over the coast into the Atlantic Ocean.

A detailed study of all these cases confirms the general conclusions already set forth in connection with my earlier paper; hence the tabulation and detailed notes are omitted from this paper, and only conclusions stated.

Of the 268 microseisms above mentioned, 74 were connected with lows moving over the Gulf of St. Lawrence; 20 of these were of sufficient amplitude to determine the period, which varied from 2·8 to 3·5 seconds, with 4 cases of 3·6, 4·6, 5·0, and 6·0 seconds respectively—68 lows moved wholly or in part over the coast of New England; of these 21 showed periods ranging from 3·0 to 3·5 seconds, with one 3·8, one 4·0, and two 5·0 seconds, the remainder being too ill-defined to allow determination of period—73 microseisms were connected with pressure changes occurring over the Middle Atlantic coast between New York City and Cape Hatteras; nearly all of these were lows and show periods ranging from 3·0 to 3·5 seconds, with 5 cases ranging from 3·8 to 5·0 seconds. There were 20 cases connected with the South Atlantic coast, nearly all being due to lows passing northeastward into the ocean and often moving northward parallel to the coast with decreasing intensity; most of these gave intense microseisms with the usual period, one case having a period of 5·0 seconds; in addition to these were 13 cases of lows forming in the Gulf, or the ocean east of Florida, also including hurricanes which approach the Florida peninsula or the Gulf coast; these show the usual periods

with one marked exception: on October 16–17 a hurricane, with pressure about 29·05 inches, was in the Gulf southwest of Florida and the microseisms had a period from 5·0 to 5·8 seconds; on the 18th, when the center had approached the Florida coast and was passing inland, the period had decreased to 3·5 seconds and the amplitude greatly increased.

In general the period of the microseisms is from 3·0 to 3·5 seconds regardless of the part of the coast under strain. Periods greater than 3·6 seconds apparently occur only when the low is of great extent and the center almost wholly over the ocean. It would appear from this that the period of the microseisms varies with the extent of the disturbed water area.

In general, pressure changes due to high areas are too gradual and widespread to produce microseisms of appreciable intensity, although about 40 cases have been noted, nearly all being cases in which a depression was closely followed by a high area of marked intensity.

In my earlier paper it was suggested that the microseisms might be connected with the movements of large masses of water set in motion by the wind accompanying the pressure changes. This assumption is not borne out by a comparison of the winds, normal to the coast line, and the microseisms occurring during the period January 1 to June 30, 1910. During this period there were strong microseisms on days when there was little or no wind along the coast, and also days when there were high winds without any well-marked microseisms. In general, high areas are accompanied by winds when they approach the coast, although they are rarely accompanied by microseisms.

Another point of interest is that the period of the microseisms does not appear to be conditioned by the geological nature of the part of the coast line over which the low is passing, as all parts of the coast give essentially the same periods. It seems probable that this period is a characteristic of the locality in which the seismograph is mounted, although the change of period during different microseisms is difficult to explain on that basis. Klotz at Ottawa observed periods of 5 to 6 seconds with occasional changes to 3 seconds.

The above conclusions by no means preclude the probability of microseisms being produced by the movement of lows and highs wholly over the land area; in fact it is extremely probable that they do occur, and could be readily recorded by a sufficiently sensitive seismograph, but it is evident that, at least for the eastern part of the United States, the most marked microseisms are those related to the variations of pressure along the coast line.

ART. XL.—*Microseisms Caused by Frost Action;* by J. E. BURBANK.

IN a paper on "Some Apparent Variations of the Vertical etc."* the writer called attention to a class of minute earth movements or microseisms of very small amplitude and irregular period varying from 8 seconds to 2 minutes. At that time only a few cases had been identified.

Recently an abstract of a paper by B. Gutenberg† has come to my attention. In this abstract it is stated that the distribution of frost in southwestern Europe up to about 60° N. Lat. and 30° E. Long. can be determined from the records of the 100 kilogram pendulum of the Geophysical Institute at Göttingen. The movement showed a well-defined daily period, max. about 6 a. m. and min. about 3 p. m. and an amplitude which on one occasion showed an earth movement in the north-south direction as great as $\frac{1}{2}$ millimeter on each side of the position of rest. One would infer that these microseisms sometimes occur when the ground at some distance is freezing and thawing, while at Göttingen it was not frozen. It is difficult to understand how the expansion and contraction of the surface layers in freezing and thawing can produce vibrations or variations of level of sufficient magnitude to be recorded more than a few kilometers beyond the frost zone.

Cheltenham is so located that the approach of cold waves and freezing of the ground can be studied several days before they reach us, and often the zone of frost is only a short distance, 100 to 200 kilometers, to the north of the station, while the ground at Cheltenham is not frozen. Our pendulums‡ are not as sensitive as those used by Gutenberg, and a movement of the earth particles of less than ·02 millimeter would not be recognized.

An examination of our seismograms for a period of several years past shows that whenever actual freezing or thawing of the ground is taking place at Cheltenham these microseisms are recorded as irregular tilts or movements of the pendulum back and forth in a somewhat jerky and irregular manner. The most common period is between 8 and 14 seconds, but they frequently have a period as great as two minutes. The amplitude increases with the intensity of the freezing or thawing, the usual range of motion of the earth particles being between ·02 and ·10 millimeters. These microseisms are con-

* This Journal, vol. xxx, Nov. 1910, p. 332.
† Physikalische Zeitschrift, 1910, pp. 1184–5.
‡ See preceding paper.

tinuous as long as the ground is frozen and continue without appreciable diminution when the frozen ground is covered with a blanket of snow. When the ground is covered with snow the microseisms are due to the thawing out of the lower layers of frozen ground in contact with the warmer layers below.

Attention was especially directed to those cases of cold waves with freezing temperatures approaching Cheltenham and in no case could any microseisms be detected until the ground at Cheltenham had begun to freeze.

The above evidence does not disprove a relation between microseisms and frost action at a distance, but it places a limit on the magnitude of such action.

Cheltenham, Md., August, 1911.

Art. XLI.—*Dahllite (Podolite) from Tonopah, Nevada; Vœlckerite, a New Basic Calcium Phosphate; Remarks on the Chemical Composition of Apatite and Phosphate Rock;* by Austin F. Rogers; with Analyses by G. E. Postma.

My attention was directed to a chemical study of apatite and related minerals by the recognition of a calcium carbono-phosphate on a mineral specimen from Tonopah, Nevada, kindly sent to me by Mr. S. C. Herold, a mining engineer. This specimen, which is from the Mizpah mine of the Tonopah Mining Company, consists of iodyrite, hyalite, quartz, manganese dioxide, and a white drusy coating of minute hexagonal crystals. As these hexagonal crystals seemed to effervesce in acid, they were provisionally referred to calcite. Optical tests failed to confirm this determination, for the fragments had weak, instead of strong, double refraction. The weak double refraction suggested apatite. As a good phosphate test was obtained, the mineral naturally was called apatite and the effervescence was attributed to an error in observation.

On reading a paper* on the probable identity of dahllite with podolite, it occurred to me that the Tonopah mineral might belong to one of these carbono-phosphates, so the solubility test was tried again very carefully. There was distinct effervescence with warm nitric acid. Observed under the microscope, the bubbles come from the hexagonal crystals and from

* Schaller, this Journal, vol. xxx, 309, 1910.

irregular fragments with weak double refraction, so the effervescence is not due to admixed calcite. Moreover, there is practically no effervescence until the acid is heated. Good tests for calcium and the phosphate radical and a slight test for chlorine were obtained. A faint test for fluorine was obtained by heating the powdered mineral with silica and concentrated sulphuric acid, and condensing the fumes on moistened black paper.*

To further prove the identity of the mineral, chemical analyses were made by Mr. G. E. Postma, chemistry student at Stanford University. Unfortunately, a very limited amount of material was available. The carbonate and phosphate radicals were determined in a large, very impure sample with these results† (average of two):

CO_3	1·56
PO_4	29·54

In a much purer sample consisting of only 74 mg., calcium, fluorine, and the phosphate radical together with insoluble matter (principally quartz) were determined with the following results:

Ca	32·56
PO_4	47·03
F	0·29
Insol.	12·72

The amount of carbonate radical in the sample can be calculated from the preceding analysis. The excess of oxygen can be obtained by subtracting the amounts of the constituents in the form given above from the amounts in the ordinary form of oxides. This oxygen excess amounts to 1·07 per cent. We then have the following figures:

		Molecular ratios		
Ca	32·56	0·814		10·00
PO_4	47·03	0·495		6·08
F_2	0·29	0·007		
(CO_3	2·48)	0·041	0·114	1·40
(O	1·07)	0·066		

The fluorine percentage is probably low, as it usually is. The ratio of Ca, PO_4, (CO_3, F_2, O) is very closely 10 : 6 : 1, slight errors probably giving high oxygen. The Tonopah mineral can be interpreted as an isomorphous mixture of $3Ca_3(PO_4)_2.CaCO_3$, $3Ca_3(PO_4)_2.CaO$, and $3Ca_3(PO_4)_2.CaF_2$. It is necessary

* Browning, this Journal, vol. xxxii, 249, 1911.

† In accordance with the modern views of chemistry, analyses are recorded in the form of metals and acid radicals.

to assume that oxygen replaces fluorine and the carbonate radical on account of the small amounts of these constituents. As the carbonate-phosphate molecule is present to the extent of at least half, the mineral should be called dahllite (or podolite).

The optical properties of the mineral are also interesting. The crystals are hexagonal tabular in habit as represented in figure 1. The interior of the crystals is almost opaque white, while the exterior is subtransparent. The central portion of

FIG. 1.

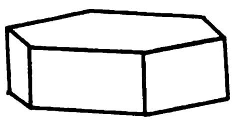
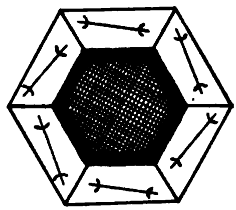


FIG. 2.



Dahllite (Podolite) from Tonopah, Nevada.

the crystals, including a narrow zone of the subtransparent part (black area of fig. 2), is dark between crossed nicols, while the remainder of the subtransparent exterior is double refracting and divided into six sectors. These sectors extinguish in opposite pairs at an angle of 7° or 8° with the edge as indicated in fig. 2 and give negative biaxial interference figures in convergent light.

The hexagonal prism is either $\{61\bar{7}0\}$ (or $\{16\bar{7}0\}$) with axial plane parallel to $\{10\bar{1}0\}$ or it is $\{10\bar{1}0\}$ with axial plane parallel to $\{61\bar{7}0\}$ (or $\{16\bar{7}0\}$), for the theoretical angle $(10\bar{1}0 \wedge 61\bar{7}0)$ is 7° 35′. If the prism is $\{61\bar{7}0\}$, as seems probable, the crystals have the symmetry of the hexagonal pyramidal or apatite class.

In the podolite described by Tschirwinsky* the biaxial sectors extend to the center of the crystal. The question arises as to whether all the Tonopah mineral, or only the exterior, is dahllite (podolite). This can not be definitely settled as the mineral contains some fluorine and also an excess of oxygen, but probably the exterior of the crystals more nearly approaches dahllite (podolite) than the interior.

The formula for podolite established by Tschirwinsky† is $3Ca_3(PO_4)_2.CaCO_3$. Schaller‡ gives good arguments for considering podolite and dahllite as identical. The name dahllite given by Brögger and Bäckström§ has priority.

* Centralblat. Mineral., etc., 1907, pp. 279–283. † Loc. cit.
‡ Loc. cit.
§ Öfv. Akad. Stockh., xlv, 493, 1888; Dana System, 6th ed., p. 866.

The isomorphism, or at least the replacement of fluorine by the carbonate radical, is proved by several analyses* of apatite taken from the literature.

	Ca	PO_4	F	CO_3	Cl
Portland, Canada	38·62	54·03	3·38	1·17	0·09
Londongrove, Penn.....	38·53	55·40	1·95	1·93	0·94
Templeton, Canada.....	37·77	55·52	1·17	3·14	0·42

The second analysis, made by Carnot,† corresponds almost exactly to the formula $3Ca_3(PO_4)_2.Ca(F_2,Cl_2,CO_3)$.

I have examined apatite from fourteen different localities and have found that, with one possible exception, they give effervescence in hot nitric acid. These include apatites from Canada, Arkansas, Norway, among them both fluor-apatites and chlor-apatites. It may seem strange that fluorine and the carbonate radical should replace each other and that the compounds $3Ca_3(PO_4)_2.CaF_2$ and $3Ca_3(PO_4)_2.CaCO_3$ should be isomorphous. The isomorphism of these compounds can be explained by the mass-effect of $3Ca_3(PO_4)_2.Ca$ (formula weight $=971$) in these compounds; the fluorine and carbonate radical have relatively little influence. This explanation of isomorphism we owe to Penfield, who explained the chemical composition of tourmaline by the mass-effect of $Al_3(B.OH)_2Si_4O_{19}$ in the molecule $H_9Al_3(B.OH)_2Si_4O_{19}$, it making little difference whether the hydrogen is replaced by aluminium, magnesium, iron, or the alkalies. The isomorphism of $PbFe_6(OH)_{12}(SO_4)_4$ (plumbojarosite) with $K_2Fe_6(OH)_{12}(SO_4)_4$ (jarosite) Penfield explained in the same way. A similar explanation will doubtless hold for other mineral groups.

A critical study of apatite analyses will convince one of the existence of a basic calcium phosphate, for many of the analyses show a deficiency of both fluorine and chlorine and also of the carbonate radical. In tabular form I have collected here several apatite analyses showing this deficiency. The oxygen is obtained by subtracting the sum of the constituents in the present form from their sum as oxides. The almost perfect summations prove that this is justified. It was thought that perhaps the carbonate radical had been overlooked in these apatites. Accordingly Mr. Postma analyzed a specimen of Zillerthal apatite, obtained from Dr. Krantz of Bonn, Germany. This apatite occurs in large white tabular crystals. Mr. Postma's analysis, which is the last one in the preceding list, shows only a slight amount of the carbonate radical.

* These and other analyses have been recalculated in the form of metals and acid radicals.

† Bull. Fr. Soc. Min., xix, 135, 1896.

	Ca	PO_4	F	Cl	H_2O	Misc.	Oxygen Defici-ency	Total
Mt. Greiner et Golling*	38·06	57·31	0·23	0·12	0·35	3·18	0·72	99·97
Krageroe, Norway†	38·96	55·24	—	0·81	0·44	3·96	1·48	100·89
Krageroe, Norway†	38·78	55·53	—	1·52	0·22	3·10	1·30	99·90
Ceylon‡	38·27	53·12	1·03	1·32	0·46	3·80	1·39	99·89
Zillerthal§	40·44	57·50	0·62	—	0·15	—	1·37	100·08
Zillerthal‖	39·83	57·07	1·20	—	0·30	CO_2=0·23	0·92	99·55

The existence of the compound $3Ca_3(PO_4)_2.CaO$ is proved by the analyses¶ of Vœlcker, Hoskyns-Abrahall, Carnot, and Postma. For a mineral with this composition or one in which this molecule predominates I propose the name *vœlckerite*, as Vœlcker was the first investigator to show that apatite was sometimes deficient in fluorine and chlorine. Hoskyns-Abrahall wrote the formula for apatite thus: $Ca_{10}(PO_4)_6(O,F_2,Cl_2)$. Groth** substitutes hydroxyl for oxygen, principally for *a priori* reasons. In the above analyses the water percentage is too low to make up the deficiency as hydroxyl, the average being 0·32 as against 1·19 for oxygen. The isomorphism of vœlckerite with fluor-apatite and chlor-apatite may also be explained by mass-effect isomorphism, one atom of oxygen replacing two atoms of fluorine.

Thus we have four isomorphous compounds:

Fluor-apatite	$3Ca_3(PO_4)_2.CaF_2$
Chlor-apatite	$3Ca_3(PO_4)_2.CaCl_2$
Dahllite	$3Ca_3(PO_4)_2.CaCO_3$
Vœlckerite	$3Ca_3(PO_4)_2.CaO$

The names fluor-apatite and chlor-apatite are well established in the literature. The name carb-apatite†† was proposed for the carbono-phosphate but was withdrawn in favor of podolite. Dahllite, however, has priority over both carb-apatite and podolite. Vœlckerite is a better name than the name oxy-apatite suggested by analogy and gives recognition to Vœlcker for his work on the chemical composition of apatite. On account of the difficulty of recognizing these minerals without chemical analysis, apatite may be used as a group name, the general formula being $3Ca_3(PO_4)_2.Ca(F_2,Cl_2,CO_3,O)$.

Besides $3Ca_3(PO_4)_2.CaCO_3$, a number of other calcium carbono-phosphates have been described. They are as follows:

* Carnot, Bull. Fr. Soc. Min., xix, 135.
† Vœlcker, Ber. Ch. Ges., xvi, 2460, 1883.
‡ Jannasch, Zs. anorg. Chem., vii, 154, 1894.
§ Hoskyns-Abrahall, Zs. Kryst., xxi, 389. ‖ Postma.
¶ In the case of the Norwegian apatites, which contain chlorine but no fluorine, there is no doubt of this, for the chlorine determination is a very accurate one.
** Tab. Uebersicht der Mineralien, 4th ed., p. 87.
†† Tschirwinsky, loc. cit.

Dahllite	$2Ca_3(PO_4)_2.CaCO_3.\frac{1}{2}H_2O$
Francolite	$Ca_3(CaF)_2(PO_4)_4.CaCO_3.H_2O$
Staffelite..........	a fibrous variety of francolite
Collophanite	$x3Ca_3(PO_4)_2.yCa.CO_3.zH_2O$

Dahllite, as shown by Schaller, is probably identical with podolite. The formula assigned to francolite seems anomalous, as it does fit into the series given above. There are but two analyses of francolite on record and they do not agree. One has 9·04 per cent CaF_2, 2·84 per cent $CaCO_3$, and no water, while the other has 7·68 per cent CaF_2, 5·10 per cent $CaCO_3$ and 1·59 per cent water. Francolite is pseudohexgonal like dahllite (podolite). The axial plane is parallel to the hexagonal outline, but this is probably not an essential difference. Lacroix regards staffelite as a fibrous variety of francolite. Additional analyses are necessary before francolite (or staffelite) can be assigned definite rank as a mineral species.

Collophanite was described by Sandberger,* who gave the formula $Ca_3(PO_4)_2.H_2O$ after deducting 3·96 per cent $CaCO_3$, which he considered to be an impurity. The analysis of Köttnitz gives $3Ca_3(PO_4)_2.CaCO_3.3H_2O$, but Lacroix† gives $xCa_3(PO_4)_2.yCaCO_3.zH_2O$. Besides the original collophanite there is only one other analysis, that of Shepard,‡ which after deducting 4·64 per cent gypsum gives $3Ca_3(PO_4)_2.H_2O$. So the composition of collophanite is not settled. There is a possibility that collophanite is an amorphous mineral with the formula $3Ca_3(PO_4)_2.CaCO_3.xH_2O$, thus bearing the same relation to dahllite (podolite) that opal ($SiO_2.xH_2O$) does to quartz (SiO_2).

Of the various carbono-phosphates only one, viz. dahllite (podolite) with the formula $3Ca_3(PO_4)_2.CaCO_3$, is, in my opinion, entitled to recognition as a mineral species.

Several suggestions as to the chemical composition of phosphate rock, phosphate nodules, and similar materials have recently been made. Stutzer§ regards phosphate rock as made up principally of amorphous calcium phosphate. Lacroix‖ believes them to be mixtures of collophanite with smaller amounts of francolite and dahllite ($2Ca_3(PO_4)_2.CaCO_3.\frac{1}{2}H_2O$). According to Cameron and Bell these materials are solid solutions of CaO and P_2O_5.

On account of the inaccuracy of the fluorine determination and on account of the water, iron, aluminium, and calcium carbonate present, analyses of phosphate rocks are difficult

* Jb. Min., p. 308, 1870.
† Mineralogie de la France, vol. iv, 56, 1911.
‡ This Journal, xxxiii, 402, 1882.
§ Die Lagerstätten der Nicht-Erze, Band I, p. 267, 1911.
‖ Loc. cit.

to interpret. It is usually impossible to decide whether the substances mentioned are essential constituents or impurities. A satisfactory explanation must account for the almost invariable presence of the carbonate radical, the usual presence of fluorine and a fairly constant ratio of 10Ca to $6PO_4$ as well as for variations in the amounts of the constituents.

An analysis by Mr. Postma of a dark brown egg-shaped nodule with radiated structure collected by Mr. R. M. Wilke in Volhynia, Russia, gave the following results:

Ca	38·81	Fe_2O_3	1·93
PO_4	46·82	Al_2O_3	3·93
CO_3	6·46	Insol.	3·22
F	none	Organic matter	1·87
Cl	tr.		

This is a typical analysis, but it contains an excess of $CaCO_3$ over that required for $3Ca_3(PO_4)_2,CaCO_3$.

The following are analyses of the purer phosphate rocks, etc.:

	Ca	PO_4	CO_3	F	H_2O	Misc.	O	Total
Naura	37·72	53·04	2·00	—	3·02	2·89	1·32	99·99
Hanau	35·27	49·17	2·46	—	2·28	9·13	1·20	99·51
Malden Island	34·63	48·43	3·23	—	5·48	7·16	1·07	100·00
Crawford Mts., Utah	36·41	48·59	2·34	0·40	1·05	8·55	1·55	98·89
Pouzillac	35·52	50·04	5·18	0·88	7·05	0·80	—	99·42
Mouillac	37·02	50·27	5·45	1·50	4·80	—	0·08	99·12
Amberg	37·28	52·93	3·78	1·90	—	3·61	—	100·00
Florida	35·62	51·93	2·25	2·46	3·03	5·01	—	100·30
Beauval	36·98	51·82	2·26	3·40	4·75		—	99·21

A few contain an excess of $CaCO_3$ over that required for the dahllite (podolite) molecule. The excess oxygen given in the next to the last column is necessary to give good summations. As phosphate rocks and nodules are not of definite chemical composition, they perhaps do not deserve recognition as minerals, but as far as can be ascertained they seem to be mixtures of fluor-apatite, vœlckerite, and dahllite (podolite) as represented by the formula $3Ca_3(PO_4)_2.Ca(F_2,O,CO_3)$. Chlorine is practically absent from these substances. The water is probably not essential, but there is a possibility of the substance $3Ca_3(PO_4)_2 . CaCO_3 . xH_2O$ or $3Ca_3(PO_4)_2 . Ca(F_2,O,CO_3) . xH_2O$, which will account for varying amounts of water.

For convenience of the reader I have given the theoretical percentages of the minerals discussed in the form of metals and acid radicals.

	Ca	PO_4	F	Cl	CO_3	O	H_2O
Fluor-apatite	39·62	56·55	3·83	—	—	—	—
Chlor-apatite	38·39	54·81	—	6·80	—	—	—
Dahllite (podolite)	38·86	55·35	—	—	5·79	—	—
Vœlckerite	40·75	57·77	—	—	—	1·48	—
Original dahllite	38·34	52·18	—	—	8·18	—	1·30
Francolite	39·07	50·62	3·40	—	5·32	—	1·59

I tested the solubility of some specimens of pyromorphite and found that several gave a distinct effervescence in hot nitric acid. Pyromorphite from the Buffalo claim on Lower Sugar Loaf creek in Marion County, Arkansas collected by Dr. J. C. Branner was analyzed* by Mr. Postma with the following results:

		Molecular ratios	
Pb	66·73	0·322	10·1
Ca	4·02	0·100	
PO_4	23·82	0·250	6·0
CO_3	1·93	0·032	1·6
Cl	2·55	0·035	
Insol.	0·42		

This pyromorphite, which is the polysphærite variety, occurs as a gray or greenish-gray crust on galena and is clearly an alteration product of the galena. It effervesces slightly in cold nitric acid. With the exception of a slight excess of the carbonate radical the analysis is very closely 10(Pb,Ca) : $6PO_4$: $1(Cl_2,CO_3)$. This analysis is considered proof that the carbonate radical may replace chlorine in pyromorphite, as there is not enough chlorine to form the pyromorphite molecule. On account of the accuracy of the chlorine determination there seems to be no doubt of this explanation. Several analyses of pyromorphite cited in Dana's System of Mineralogy show a deficiency in chlorine which may be explained by the presence of either the carbonate radical or oxygen.

In conclusion I may say that this paper makes no pretense to a final solution of the difficult problem of the chemical composition of apatite, phosphate rock, etc. Many accurate analyses will be necessary for that task.

Stanford University, California,
February, 1912.

* A closely agreeing analysis is given in Vol. V (p. 87) of Arkansas Geological Survey Reports.

ART. XLII.—*The Distribution of the Active Deposit of Radium in an Electric Field*; by E. M. WELLISCH and H. L. BRONSON.

by E. M. WELLISCH and H. L. BRONSON.

1. *Introductory.*

THE present paper contains the results of a series of experiments which were carried out at the Sloane Physical Laboratory of Yale College, and which were undertaken with a view of throwing light on the mechanism involved in the transmission of the active deposit of radium to the electrodes in an electric field or to the exposed solid surfaces in the absence of such field. In order to account for this transport of activity one of us* had already suggested a theory in which the view was taken that the transmission was effected as a result of the interaction between the active deposit particles (or restatoms) and the ions formed in the gas by the radiation accompanying the radio-active disintegration; in particular, an attempt was made to explain on this theory the experimental result obtained by Rutherford† and Franck‡ that the restatoms moved through the gas with the same velocity as the positive ions.

The original object proposed in the present experiment was to ascertain whether the distribution of activity on the electrodes could be affected in any way by the application of an extraneous source of ionization such, for instance, as that produced by causing intense Röntgen rays to pass through the gas.

We might be permitted to anticipate here the results of the present experimental investigation and to state that, although the application of such extraneous source of ionization has so far been found to produce little or no effect on the distribution of activity, nevertheless a decided interaction has been found to take place between the restatoms and the ions produced by the radiations which accompany the formation of these particles.

The results of previous experimenters with regard to the distribution of the active deposit under various conditions have shown a lack of agreement which in our present experiments has been traced to the fact that the potentials employed were often far from sufficient to saturate even approximately the radio-active ions.

* Wellisch, Verh. Deutsch. Phys. Ges., xiii, p. 159, 1911.
† Rutherford, Phil. Mag. (6), v, p. 95, 1903.
‡ Franck, Verh. Deutsch. Phys. Ges., xi, p. 397, 1909.

2. *Experimental Procedure.*

The radium emanation used in our experiments was obtained from two sources, for the use of both of which we are indebted to the kindness of Prof. Boltwood. One source consisted of a solution of radium salt contained in a glass vessel so constructed as to permit vigorous bubbling when a current of gas was passed through it; the other source was a quantity of carnotite contained in a glass jar, which was adjusted to permit of rapid connexion to the testing vessel.

The emanation was in most cases passed through glass-wool and phosphorus pentoxide before entering the test vessel; no effect on the distribution was observed, however, by omitting these precautions.

Different forms of test vessels were employed; the vessel which was used practically throughout and to which all our experiments apply, unless mention is made to the contrary, consisted of a brass cylinder with an aluminium bottom and a brass central electrode sprung into a stout brass holder so as to permit of rapid detachment. The vessel was provided with a guard tube which was connected to earth; this guard tube was slightly tapered so as to make a good fit with the ebonite plug which supported the central electrode. Stop-cock grease was employed to ensure complete tightness.

The dimensions of this vessel were as follows:

Height of containing portion............	140 mm
Inner diameter..........................	58 "
Exposed length of central electrode.....	101 "
Diameter of central electrode............	1·83 "

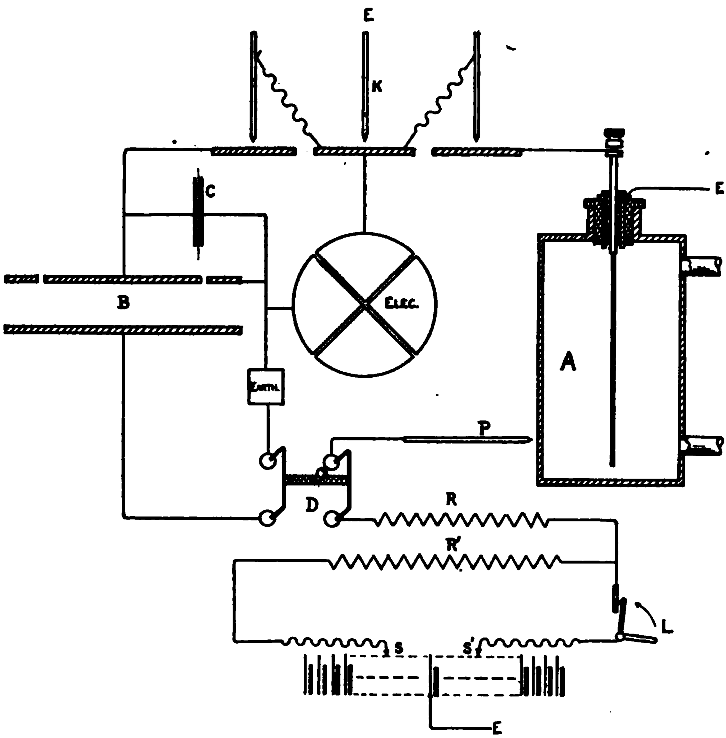
The measurements of the activity of the central electrode were made in a vessel identical to the above except that, as mentioned below, no ebonite and in consequence no guard tube was employed.

The diagram of connexions and the disposition of apparatus are given in fig. 1. The test-vessel A was supported by brass clips mounted on ebonite; these clips were connected to the battery through carbon resistances R, R′, the changes of potential being effected by means of the adjustable contacts *s*, *s*′, and the key L. B represents a parallel plate vessel which was employed in order to communicate definite induced charges to the electrometer system whenever occasion arose. C is a capacity consisting of two thin sheets of tinfoil separated by a thin sheet of mica; this capacity, together with that of B, could be added to the system by means of the key K, and the total capacity of the system was then increased $21\frac{1}{2}$ times. The electrometer was of the Dolezalek pattern with a platinum

suspension. The needle was charged to a potential of 120 volts, and with this potential the sensitiveness was 180^{mm} per volt on a scale about 1 meter distant.

The Röntgen-ray bulb, which was enclosed in a lead-covered box and which was employed whenever it was desired to increase the ionization current in the test-vessel, is not shown

FIG. 1.



in the diagram; the rays were admitted through an aperture in the lead directly beneath the aluminium bottom of the vessel.

For potentials up to 1200 volts a battery of small accumulators was employed. For the larger potentials a Wimshurst machine was used which was driven by an electric motor; it was found that the voltage obtained by this means was surprisingly steady, although the slight variations were sufficient to prevent any accurate measurements of the ionization current through the gas. The voltage was regulated by means of an

adjustable spark-gap, and was measured with a Braun electrometer.

The method of procedure was in general as follows: after the introduction of the emanation the vessel was allowed to remain in position under the desired conditions of potential, pressure, etc., for a period sufficiently long to enable the emanation and the resulting activity to get into equilibrium. This period was usually about three hours, and was never less than $1\frac{1}{2}$ hours; readings of the ionization current were taken at intervals so as to note the growth of activity and the establishment of equilibrium. The emanation was blown out by means of a strong current of air from a force-pump; the ebonite plug containing the central electrode was removed, care being taken that this electrode did not touch the case.

The activity on the case was measured by observing the ionization current to which it gave rise; for this purpose a fresh electrode was suspended in the vessel by means of the brass holder shown in the diagram; by thus avoiding the use of ebonite the activity could be measured with great precision. This procedure was rendered necessary because, as is subsequently shown, an accurate determination of the activity on the case was the most important factor in the experiments. It was found that handling ebonite insulation, even with great precaution, resulted in the production of disturbing electrical effects which were sufficient to render uncertain the subsequent measurements. The activity at any time after the removal of the emanation was then measured by observing the electrometer rate.

In order to determine the activity on the central electrode this electrode was removed from its holder by means of a pin, which passed through a small hole, and was then suspended in the second vessel in the same manner as described above; the electrometer rate could then be taken at any definite time dating from the removal of the emanation.

In practice it was found convenient to measure the case activity at 10, 15, and 20 minutes, and the central electrode activity at 25, 30, and 35 minutes after the emanation had been removed; the maximum activity, *i. e.* the activity when in equilibrium with the emanation, was then calculated by means of the figures given by one of us* for the rate of decay of the activity resulting from a long exposure. The consistency of this calculated maximum determined the number of readings necessary for the measurement of the activity, but usually those just mentioned amply sufficed.

* Bronson, Phil. Mag. (6), xii, p.73, 1906. In order to calculate the maximum activity from the rates determined at the times given above, the observed rates have to be multiplied by the factors 2·02, 2·25, 2·41, 2·58, 2·75, and 2·96 respectively.

In practically all our experiments the activities were measured by observing the ionization currents to which they gave rise in air under the ordinary conditions when a potential of +160 volts was applied to the vessel employed. Although this potential was not sufficient to saturate the currents, subsequent experiments showed that the ratio of the two activities as thus measured was not altered by using a larger voltage.

A typical set of readings is given later.

3. *Experiments with Small Applied Potentials.*

It is well known that for moderately high potentials the activity is concentrated to a very large extent on the negative electrode in an electric field; Schmidt* has shown that when small potentials are employed the cathode activity decreases in a manner analogous to the diminution in electric current which follows as a result of recombination of ions; in fact, he came to the conclusion that the active deposit particles behave in a manner similar to the positive ions. The first set of experiments tried in the present series had as object to find whether the amount of activity that was deposited on the cathode when a small positive potential was applied to the case could be altered when the ionization in the gas was so increased by means of Röntgen rays that the electric current through the gas was at least as great as if a large potential had been applied without any extraneous source of ionization.

In this set of experiments the rods were exposed as cathodes to the process of activation for a period of 10 minutes, both with and without the application of Röntgen rays, the testing vessel containing air at 1 atmosphere; the activities were measured at various intervals after removal, and were then directly compared. Preliminary trials which were made showed that in the process of removing one rod and substituting another less than 2 per cent of the emanation escaped.

A result of one set of measurements is given below:

With +4 volts on case and 10 minutes exposure, activity of cathode 10 minutes after removal is represented by an electrometer rate of $1 \cdot 1^{mm}$ per sec.

With same applied potential and strong Röntgen rays passing through the vessel during the whole time of exposure, the corresponding rate was ·88.

As a rough idea of the relative currents involved the following figures are given; in these instances the rates were determined with the extra capacity added to the system.

Ionization current immediately after introduction of emanation and with +160 volts on case: 33^{mm} per sec.:

with 4 volts rate was 1·05;

with 4 volts and Röntgen rays rate was 5·21.

* Schmidt, Phys. Zeitschr., ix, p. 184, 1908.

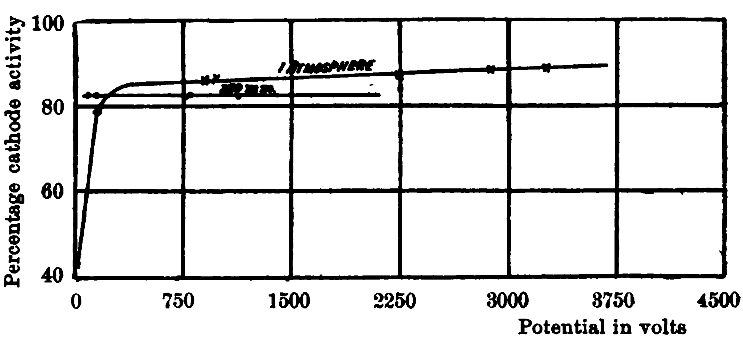
In the last two instances there was, of course, a deposit of activity on the walls of the vessel.

Other experiments were made with the same object, in some instances large amounts of activity being previously concentrated on the walls of the vessel so as to increase still further the ionization. The results were of the same nature, viz., to show a small decrease in the amount of activity deposited on the cathode when additional ionization was produced; the decrease could be accounted for if we adopt the view that the restatoms behave as positive ions, and are subject to increased recombination with the negative ions produced by the application of the extraneous radiation.

4. *Experiments with Larger Potentials. Air at 1 atmosphere.*

Experiments were next made to ascertain the percentage of the total activity that was deposited on the cathode when larger positive potentials were applied to the case. The result of this set of measurements is given below (Table I), and is exhibited as a curve in fig. 2, which refers to air at 1 atmosphere; the

Fig. 2.



method of procedure for determining the points has already been given in section 2.

It will be seen from an inspection of this curve that the percentage cathode activity always increased with the applied potential, a result which indicates that there are practically no negative carriers of activity; all the so-called anode activity to which reference is made by many investigators is due to the diffusion to the walls of the vessel of uncharged restatoms. A slight correction has on this account to be made for the amount of uncharged activity that diffuses to the cathode during the exposure; this correction was made by estimating the relative areas of the exposed surfaces of cathode and case, which were found to

TABLE I.

Emanation in Air at 1 Atmosphere.

Potential in volts	Percentage cathode activity
18	42·7
160	79·1
900	85·9
975	86·6
2250	86·9
2800	88·5
3250	89·0
4000	91·3

be in the ratio 1 : 50, and assuming that the uncharged restatoms were distributed in this proportion. The true percentage cathode activity, that is, the number of positive carriers expressed as a percentage of the total number of carriers, is obtained from the percentage cathode activity (p), as determined experimentally, by evaluating the expression $\frac{51p}{50} - 2$. All values given in this paper for the percentage cathode activity denote the true percentage obtained by correcting in this manner.

A typical set of measurements is given below:

Emanation passed through P_2O_5 and glass-wool into vessel containing air at 1 atmosphere. +975 volts on case. Exposure about 2 hours.
Equilibrium rate with added capacity: 6·17.
Activity on case measured at 10 and 15 minutes after removal of emanation; rates with added capacity: ·19 and ·17 respectively.
Activity on cathode measured at 20 and 25 minutes after removal of emanation; rates with added capacity: 1·05 and ·98 respectively.
Calculated maximum activity on case: ·38.
Ditto cathode: 2·53.
Ratio of max. cathode to max. case activity: 6·66 : 1.
Percentage cathode activity: 86·9.
True percentage cathode activity as corrected for diffusion of uncharged carriers to cathode: 86·6.

It is difficult to estimate with precision the experimental error in the determination of the percentage cathode activity. A slight error probably arises from the fact that the cathode

and case activities are determined by means of ionization which is differently distributed. This has been shown experimentally to have a negligible effect on the relative values of the percentage cathode activities for different potentials, the determination of which was really the object of the experiment. As mentioned above, it was important to make an accurate determination of the maximum activity on the case. An error in the determination of this activity leads to approximately the same percentage error in the determination of the percentage cathode activity; this error in all our experiments is probably less than 2 per cent.

The plotting of a curve such as that of fig. 2 is obviously only possible if the percentage cathode activity is independent of the amount of emanation used in the experiment. This fact was demonstrated repeatedly during the course of our investigations; as an instance of the wide range over which this holds it may be mentioned that the percentage cathode activity was the same with 900 volts on the case when the amounts of emanation in the vessel were such as to afford equilibrium rates of 5·32 without any added capacity and 16·1 with the added capacity, *i. e.* rates which are roughly in the ratio 1 : 65. When we are working in the earlier part of the curve, *i. e.* with relatively small potentials, this independence no longer holds good; but for the higher potentials the effect of the amount of emanation within a large range becomes negligible.

The curve bears a striking resemblance to the curves which have been experimentally determined for ionization by α-particles. Many observers have drawn attention to the "lack of saturation" which is a marked feature of such curves; in particular, this phenomenon has been the subject of special investigation by Bragg,* Kleeman,† Moulin,‡ and Wheelock.§ Reference is made to this point later (section 7). The similarity was so striking as to suggest a more detailed study of the ionization curves for emanation in equilibrium and with different applied potentials.

It was found that within the limits of error the ratio of the two ionization currents obtained for two potentials not too low‖ was, like the percentage cathode activity, independent of the amount of emanation in the vessel; and, moreover, that

* Bragg, Phil. Mag. (6), xi, p. 466, 1906.

† Kleeman, Phil. Mag. (6), xii, p. 273, 1906.

‡ Moulin, Compt. Rend., cxlviii, p. 1757, 1909; Le Radium, vii, p. 350, 1910.

§ Wheelock, this Journal, xxx, p. 233, 1910.

‖ The potentials should be sufficiently large to prevent volume recombination, as distinguished from columnar recombination, *i. e.* should be sufficient to saturate a uniform distribution of Röntgen-ray ions equal in number to those produced by the α-radiation.

this ratio was identical with the ratio of the percentage cathode activities corresponding to these two potentials.

As an example of the results obtained in this connection it will suffice to compare the ratio 1·09 of the percentage cathode activities obtained with potentials 975 and 160 volts respectively with the corresponding ionization currents. From our values for the ionization currents in air at 1 atmosphere pressure obtained in three experiments when widely different quantities of emanation were employed, we deduce the following figures:

Ratio of current with V volts to that with 160 volts:

$$=1{\cdot}10 \text{ when } V=875,$$
$$=1{\cdot}10 \text{ when } V=980,$$
$$=1{\cdot}07 \text{ when } V=900.$$

It would serve no useful purpose to reproduce in full any of the ionization curves because, in the first instance, the early slope of the curve depends markedly on the amount of emanation employed, and, secondly, because the comparison could only be made over the limited range from about 100 to 1000 volts, as the ionization current could not be accurately measured when the larger potentials were employed.

That the equality of the ionization and activity ratios still holds approximately at low voltages when a constant amount of emanation was employed was verified by measuring the percentage cathode activity with 18 volts applied, and the ionization currents for 18 volts and higher potentials, it being known that the percentage cathode activity at the higher potentials was independent of the amount of emanation in the vessel. The following results were obtained:

Percentage cathode activity with	18 volts:	42·7
Ditto	160 volts:	79·1
Ratio: ·54		
Ionization current with	18 volts:	6·6
Ditto	160 volts:	11·4
Ratio: ·58		

The agreement is only rough, and further experiments will be necessary at these small potentials.

The percentage cathode activity increases so slowly with the higher potentials applied that it appeared as if some definite fraction of the activity was always bound to be deposited on the case. Subsequent experiments made with large potentials obtained by using the Wimshurst machine showed, however, that the percentage cathode activity continually increased with the potential. It is not out of place to mention briefly here two sets of experiments which were conducted prior to the use of the Wimshurst machine.

It was suggested that, if a large uniform electric field were applied, possibly the number of uncharged carriers might become insignificant. For this purpose the emanation was introduced into a vessel consisting of two parallel electrodes of aluminium (each 58^{mm} in diameter) insulated by an ebonite ring 20^{mm} thick; the vessel contained air at a pressure of 1 atmosphere. Experiments made with applied potentials of 160 and 1000 volts gave values of 75 and 82·6 respectively for the percentage of positively charged carriers.

The second set of experiments had as object to determine whether RaA was deposited on the case. To test this point the cylindrical vessels were employed as usual and large potentials applied, but exposures of only 1 minute' duration were made. It was found that the resulting curve of decay of the case activity had the characteristic properties of the curves of decay for the activity due to a short exposure to the radium emanation.

Mention might also be briefly made here of some experiments which were performed to ascertain whether there was any alteration in value of the percentage cathode activity resulting from a long exposure with large positive potentials applied to the case when throughout the exposure the ionization current was greatly increased by the passage of Röntgen rays through the vessel. The alteration, if any, was very small, and for the present, at any rate, we must assume that the action of the Röntgen rays is without effect on the distribution of the activity.

5. *Experiments with Air at Reduced Pressure.*

The experimental results described in the preceding section strongly suggest that over a wide range of potentials the percentage of the total activity which is deposited on the case represents the percentage lack of saturation of the positive ionization current. These experiments related to the activity distribution in air at a pressure of 1 atmosphere. Now Moulin and Wheelock have shown (*loc. cit.*) that the ionization produced by α-particles is more readily saturated when the pressure of the gas is reduced; it was, therefore, of interest to determine whether the percentage cathode activity would follow the positive ionization current when the gas pressure was reduced. For this purpose the emanation was introduced into the testing vessel, which contained air at a pressure of 260^{mm}, and the percentage cathode activity was determined for various applied positive potentials. The results are given below (Table II), and are exhibited as a curve in fig. 2.

TABLE II.
Emanation in air at pressure of 260^{mm}.

Potential in volts.	Percentage cathode activity
80	82·5
150	82·5
775	81·8
790	82·2
1130	81·8
2250	83·8
2250	84·2

It is noticeable that although the percentage cathode activity for 150 volts is greater than the corresponding value for a pressure of 1 atmosphere, nevertheless when the higher potentials are reached the values are smaller at the lower pressure.

When the ionization due to the emanation in equilibrium with its activity and in air at a pressure of 260^{mm} was measured for various applied positive potentials, it was observed that the alteration of ionization with potential was so extremely slow as to suggest saturation. Over the range for which the ionization could be measured this alteration was too small to justify comparison with the figures given for the percentage cathode activity; the striking feature is that both curves approach more nearly to the horizontal than the corresponding curves for a pressure of 1 atmosphere. The figures for the lower pressure show that for large potentials the activity is farther from saturation than at 1 atmosphere; it is therefore only reasonable to conclude that in the case of ionization the percentage lack of saturation is greater at the lower than at the higher pressure.

The figures given in Table II, although sufficiently consistent to justify the conclusion just given, nevertheless exhibit slight irregularities which are being made the subject of further investigation. In the first instance the values for the percentage cathode activity for potentials in the neighborhood of 1000 volts show a slight falling off as compared with those corresponding to the smaller potentials. The explanation of this effect appears to lie in a distortion of the field in the neighborhood of the ebonite plug, arising from some action of the a-radiation on the ebonite; this distortion would result in some of the cathode activity being deposited on the plug instead of on the central electrode. Corresponding difficulties arose for the ionization measurements at the reduced pressures.

The increase of the percentage cathode activity in the neighborhood of 2000 volts is probably real, although the number of experiments in this connection is not yet sufficient to justify any definite statement. It is, however, of interest to record that throughout the exposure with these high potentials a large current due to ionization by collision was passing through the gas.

Finally, it might here be mentioned that a complete set of observations for the distribution of the activity with various applied potentials, both for air at 1 atmosphere and for air at a pressure of 250^{mm}, had previously been made, using the same test-vessel, but with the guard-tube projecting a short distance into the volume of the gas. By reason of this some of the activity which belonged properly to the cathode was measured as "case activity," so that the resulting values for the percentage cathode activity were too small. The curves obtained both for activity and ionization exhibited the same general features as those previously described. Some of the results obtained are given below; these figures are not comparable with those given above, which were all obtained after the guard-tube had been cut down.

Emanation in Air at 1 atmosphere.

Potential in volts	Percentage cathode activity
160	76·2
880	84·1
2750	86·2

Emanation in Air at 250^{mm} pressure.

Potential in volts	Percentage cathode activity
160	81·2
920	81·9
2500	82·1

6. *Experiments with Air at Pressures greater than 1 atmosphere.*

Several experiments were performed to ascertain the distribution of activity when the air in the testing vessel was at a pressure greater than 1 atmosphere. The results are given in

Table III: they were obtained in the early stages of the research when little information was at hand concerning the distribution of the activity for various potentials. For this reason the experiments appear very unsystematic; however, the results will serve to convey a good idea of the difficulty of obtaining approximate saturation of the activity, even with large applied potentials.

TABLE III.

Pressure, atm.	Potential in volts	Percentage cathode activity
1·6	+700	68·8
2·0	650	64·1
2·5	160	55·2
2·5	750	60·1
3·13	880	57·5
3·33	3750	80·6
3·53	750	53·8

The difficulty of saturating the ionization current through the gas likewise made itself manifest at these pressures; as an example it may be mentioned that with an applied potential of 1100 volts the ionization current due to a constant source of radiation increased as the pressure was increased from 1 to 2½ atmospheres, and then continually decreased with any further increase in the pressure.

These considerations afford an explanation for the maximum of cathode activity which has been found by several experimenters to set in at certain pressures when a constant potential is employed.

No indication of any decided effect upon the distribution of the activity was obtained by subjecting the gas throughout the exposure to the influence of a strong source of Röntgen rays. In this experiment the vessel contained emanation in air at a pressure of 3⅛ atmospheres; the applied positive potential was 1100 volts; the equilibrium rate with added capacity was 5^{mm} per sec., and with the Röntgen rays acting was 25^{mm} per sec. The percentage cathode activity was 56·2, which is of the order that might have been expected from the previous results.

7. *Discussion of Experimental Results.*

In the interpretation of the experimental results which have been obtained in connection with the distribution of activity the question arises immediately: what is the reason for the

difficulty in saturating the cathode activity? Even under the most favorable conditions which have been employed in our work there is still about 10 per cent of the activity deposited on the walls of the testing vessel. In an attempt to answer this question we are at once led to the corresponding problem in connection with the ionization current which passes through the gas during the activation of the electrodes. Mention has already been made of the researches of Bragg, Kleeman, Moulin, and Wheelock in connection with this aspect of the problem. Bragg explained the difficulty of saturating the ionization due to a-particles by introducing the conception of initial recombination; viz., that the electron which is expelled in the process of ionization returns in a number of cases to its parent atom, and exceptionally strong electric fields are needed to exercise any appreciable preventive effect upon this tendency to recombine. Kleeman extended the experimental work, using Bragg's theory as a basis. Moulin ascribed the difficulty of obtaining saturation to the fact that the a-particles ionized in columns, so that the density of ionization is not uniform throughout the gas when sufficiently small volumes of gas are considered. This localization of the ions would naturally result in a recombination more intense than that which would correspond to a uniform distribution in the usual acceptation of the term. Moulin showed that saturation appeared to be most difficult when the columns were parallel to the lines of force of the electric field; when, however, the a-particles moved across the lines the ionization tended more readily to saturation. Wheelock continued the work, adopting the idea of columnar ionization; in particular, he showed that when the pressure was reduced to about one-third of an atmosphere saturation set in fairly readily. There can be little doubt as to the reality of this columnar effect and the intense recombination resulting from the local distribution of the ions; this is clearly brought out by the slowness with which the ionization current increases with the potential in the early stage of any curve for a-particle ionization. The experimental results obtained in the present research appear to lead to a radically different explanation of the shape of the ionization curves at the higher potentials. It has been shown that for potentials which are not too low the ratio of the percentage cathode activities for two different potentials is equal to the ratio of the corresponding ionization currents due to the a-particles, and over a wide range is independent of the amount of emanation employed, that is, of the intensity of the intrinsic ionization. This experimental result has already led to the suggestion that the fraction of the total activity which is deposited on the walls of the testing vessel is a measure of the lack of saturation of

the ionization current, so that in general the percentage case activity is equal to the percentage lack of saturation of the current. The values given in section 5 for the percentage cathode activities at a pressure of 260$^{\text{mm}}$ are smaller for the higher potentials than the corresponding values for atmospheric pressure; we are consequently constrained to regard the percentage lack of saturation as being greater for the ionization currents at the lower pressure than at the higher pressure. The horizontality of the curves would thus appear to furnish no evidence as to the degree of saturation. The curves both for activity and ionization current do not appear to have horizontal asymptotes such as belong to the ordinary saturation curves for Röntgen-ray ionization. We must rather look upon the curves as having a continued upward slope, even when we are considering the ionization curves corresponding to low pressures. This upward slope suggests that extra ionization is produced by the electric field after the α-particle has ceased to ionize.

On this view there must be present in the gas certain molecules, or neutrons, which are in a condition allowing of relatively easy ionization. It is highly probable that the molecules have already been put in this unstable condition by the action of the α-particle; we may look upon this condition as the result of ineffectual attempts by the α-particle at ionization, possibly as the result of actual ionization immediately succeeded by initial recombination. However, these molecules are left by the α-particle in an electrically neutral although unstable condition, and a certain number of them are afterwards resolved into ions, probably as a result of collision with the ions already established in the columns.

These neutrons are in all probability formed most numerously during the early part of the range of the α-particle, when it is moving with its largest velocity. The approximately horizontal parts of the ionization curves such as are obtained at low pressures, or when the α-particle moves perpendicularly to the lines of electric force, would therefore only represent saturation in the sense that all the free ions have been brought over to the electrodes because in these cases it is unlikely that an appreciable number of neutrons would be resolved into ions.

As far as the active deposit particles are concerned we may regard them as neutral restatoms which have been exposed to the action of the α-particle at the moment of disintegration of the emanation atom; we would thus expect them to be for the most part radio-active neutrons which have in general to be subjected to further influence before acquiring a positive charge.

Experiments which are now in progress suggest also that the shape of the Bragg-Kleeman ionization curve can be accounted

for by the formation of neutrons and ions in different proportions along the entire range of the α-particle.

8. *Summary.*

(1) The distribution in an electric field of the activity resulting from a long exposure to the emanation of radium has been determined for various conditions of pressure, potential, etc.

(2) There appear to be no negatively charged carriers, all the so-called anode activity being due to the diffusion of uncharged carriers.

(3) The effect on the distribution obtained by causing Röntgen rays to pass through the gas during the exposure has been investigated; this effect was appreciable only when the activity and ionization were far from saturation.

(4) The difficulty of obtaining saturation both for the cathode activity and for the α-ray ionization currents has been explained as being due to the formation by the α-particle of neutrons, some of which are subsequently resolved into ions, probably by collision with ions already established in the columns.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Melting-point of Spodumene.*—ENDELL and RIEKE have made some new observations upon this subject and have drawn interesting geological conclusions from their results. They used spodumene from Branchville, which appears to be much purer than the material from Stirling which has been used by Doelter for melting-point determinations. The authors find that the mineral, when heated for an hour or more to about 950° C., changes its specific gravity from 3·147 to about 2·37, a gain in volume of 24 per cent. At the same time, between 920° and 980° C., the monoclinic substance loses its double refraction and acquires a lower average index of refraction; and the heating-curve shows a change at nearly the same temperature. It was found that the material must be finely powdered to show these changes accurately. The authors consider 950° C. as the true "melting-point" of spodumene, although it is perfectly hard and solid at this temperature and it does not actually fuse until a temperature of about 1380° C. is reached. They do not admit the existence of a solid, isotropic modification of the mineral, because there is no difference between the specific gravity and index of refraction of the unfused solid and the glass.

Since spodumene occurs at Branchville, Conn., in a pegmatite vein, the authors suggest that it may serve as a measure of geological temperature, as they believe that it could not be formed above about 950° C. They consider the effect of pressure as practically of little importance, since from Clapeyron's formula they calculate the effect as only 7° C. per kilometer in depth.—*Zeitschr. anorgan. Chem.*, lxxiv, 33. H. L. W.

2. *The Detection of Nitric Acid in the Presence of Nitrous Acid.*— SEN and DEY have found that hydrazine reacts with nitrous acid according to the following equations:

$$N_2H_4 + 2HNO_2 = N_2 + N_2O + 3H_2O$$
$$N_2H_4 + HNO_2 = NH_3 + N_2O + H_2O$$

They have, therefore, used hydrazine sulphate for the purpose of removing nitrites, in order that nitrates, upon which the reagent has no action, may be detected. The method appears to be much more accurate than that of Piccini, which depends upon the removal of nitrous acid by means of urea in the presence of dilute sulphuric acid, because this reaction is not rapid enough to prevent the formation of traces of nitric acid from the spontaneous decomposition of the free nitrous acid. The hydrazine method has the advantage that the nitrous acid does not need to be set free by another acid, since the sulphuric acid combined with the hydrasine furnishes sufficient acid for the decomposition of the nitrite, and moreover the reaction goes so rapidly that no nitric acid can

be formed. Experiments with pure sodium nitrite showed that there was no odor of nitrous gases in the nitrogen escaping from the reaction with hydrazine sulphate, and that the solution after the reaction was complete gave no test for nitric acid with diphenylamine in concentrated sulphuric acid. — *Zeitschr. anorgan. Chem.*, lxxiv, 52. H. L. W.

3. *The Chemical Constitution of Ilmenite.* — W. MANCHOT has made analyses of a massive titanic iron ore from Ekersund in Norway and a crystal of ilmenite from the Urals. The results in the two analyses are very dissimilar, and the ilmenite analysis is incomplete, but the latter is of some interest because the ferric oxide was determined by dissolving the substance, out of contact with air, in hydrochloric acid and using iodimetry. This determination indicates that the ratio of TiO_2 to FeO approaches 1 : 1. This is used as an argument in favor of the ilmenite formula $TiO_2.FeO$, and in opposition to the view that it is a mixture of Ti_2O_3 and Fe_2O_3. It appears that the same formula was indicated much more satisfactorily by the work of Penfield and Foote (this Journal, iv, 108, 1897). The author has attempted to show by direct experiment that Ti_2O_3 is not contained in the mineral by demonstrating that the powdered samples when boiled either with alkalies or acids evolve no hydrogen gas. Although the author considers these experiments to be conclusive, it does not appear that this is the case, for if a titanous salt and a ferric salt were formed at the same time it is perfectly well known that, at least in acid solution, the ferric salt would be reduced, and if the ferric salt were in excess no hydrogen could possibly be given off. In the case of alkalies, if any reaction at all occurred, it might happen that nascent hydrogen would reduce ferric oxide instead of forming a gas.—*Zeitschr. anorgan. Chem.*, lxxiv, 79. H. L. W.

4. *Determination of Alkalies in Silicates.*—For this determination E. MÄKINEN has used fusion with about 10 parts of calcium chloride in the place of J. Lawrence Smith's method. The platinum crucible in which the fusion is made is placed in a hole in a piece of asbestos board in such a way that only the lower half of the crucible comes in contact with the flame. This part of the crucible is gradually brought to a full red heat by means of a Teclu burner, and so maintained for 25 or 30 minutes. The treatment is then similar to that usually employed in Smith's method. Specially prepared calcium chloride was required, as the commercial product was found to contain alkalies. The results with several feldspars and rocks were good, but it appears to the reviewer that, on account of the very large amount of calcium chloride going into solution, which necessitates a double precipitation of calcium carbonate, the process will not replace the usual one.—*Zeitschr. anorgan. Chem.*, lxxiv, 74. H. L. W.

5. *A Dictionary of Applied Chemistry;* by SIR EDWARD THORPE, C.B., LL.D., F.R.S., assisted by Eminent Contributors. Revised and Enlarged Edition in Five Volumes. Volume I (A–

CHE). 8vo, pp. 758 ; London, 1912 (Longmans, Green and Co.). —Twenty-two years have elapsed since the first edition of this well-known book of reference made its appearance as a companion to Watts' Dictionary. During this period chemistry has advanced to such an extent in its applications to the arts and manufactures that a complete revision and a great enlargement of scope in the present edition have been necessary. It will consist of five volumes in the place of the original three volumes.

An inspection of the new volume shows evidence of thorough work on the part of the contributors, who have been selected not only from the United Kingdom but also from America, Germany, Switzerland, etc. The work appears to have been thoroughly revised and modernized, particularly as far as the topics in which great advances have been made in the last two decades are concerned. No detailed review of a book of such magnitude and complexity can be attempted here, but a few of the prominent and interesting articles in the present volume may be mentioned, such as "Acetylene as an Illuminant," "Analysis," "Aluminium," "Brewing," "Carbohydrates," and "Cellulose." H. L. W.

6. *On the Properties of the Rays Producing Aurora Borealis.* —It has been generally assumed that auroræ are caused by electromagnetic disturbances in the earth's atmosphere due to radiations from the sun, but the precise nature of these radiations has not been established heretofore. An appreciable advance towards the solution of the problem has been made by L. Vegard, who starts with the hypothesis that the incident radiations are small electrified particles or rays. The straight-lined streamers of the auroræ would require a radiation which is but little scattered and this condition is fulfilled by α-rays and not by β-rays. The abruptness with which the luminosity stops at the lower edges of the streamers corresponds to the well-defined range of α-particles in a gas. The ionization, due to a homogeneous pencil of α-rays, is known to increase as the speed decreases, attaining a maximum value near the point where the rays are stopped. This fact has its counterpart in the increase in luminosity observed near the lowest parts of auroral bands and streamers. By comparing the altitudes at which the α-rays from various radio-active substances would be stopped by the earth's atmosphere with the observed heights of auroræ, Vegard shows that the agreement is as good as can be expected from the data at hand. The parallel, drapery bands can be accounted for by the assumption of groups of homogeneous rays from the same source. A mathematical investigation of the paths which would be followed by charged particles entering the earth's atmosphere from the sun, leads to the conclusion that a positive charge is most consistent with the observed positions of auroræ. Thus it is seen, that the majority of auroral forms may be explained on the assumption that they are due to α-rays emitted by radio-active substances of the sun.—*Phil. Mag.*, xxiii, p. 211, February, 1912. H. S. U.

7. *The Pressure of a Blow.*—In a discourse delivered at the Royal Institution on January 26, Prof. Bertram Hopkinson

gave some very striking figures and described some highly interesting phenomena associated with blows produced in various ways. An account of only a few typical cases may be here presented.

Suppose that each of two equal billiard balls has a speed of eight feet per second and that they are moving towards each other along their line of centers. At the very instant of touching there is, of course, no pressure between the balls, but as the centers continue to approach, each sphere becomes flattened at the region of contact. This region is circular and it rapidly increases in area until the balls as wholes are brought to rest, that is, until the work done against the elastic forces of restitution is equal to the original kinetic energy of the system. For the case in question the distance of approach is 14/1000 of an inch and the force equals 1,300 lbs. The circle of contact has a diameter of one-sixth of an inch, so that the average pressure amounts to 27 tons per square inch. The distribution of pressure, however, is not uniform, the pressure at the center of the areas of contact being 1 1/2 times as great as the average pressure. The subsequent behavior of the spheres is of no interest in this connection. If very hard, hollow steel balls, having the same mass as the ivory spheres, are caused to collide with a relative speed of 16 feet per second, the distance of approach will be less, the area of contact smaller, and the maximum pressure much greater than for the billiard balls. This pressure when averaged over the circle of contact attains a value of 280 tons per square inch. These results of theoretical computation for steel balls have been verified by comparing the calculated time of contact with the interval obtained experimentally by the aid of appropriate electrical apparatus. The time of contact for the ivory spheres, mentioned above, was 1/4000 of a second.

A case involving an inelastic substance is afforded by the impact of an elongated lead rifle bullet against a hard steel plate. Under the enormous pressures developed lead flows very freely, so that, in the absence of any lateral support, each cross-sectional disc of the bullet maintains its speed practically unchanged until it comes in direct contact with the steel. The pressure exerted by the bullet is, probably, sensibly constant, since it depends upon the square of the speed, but not upon the length or diameter of the projectile. Increase in diameter only alters the area over which the force is applied, and increase in length the time during which it acts. As a practical example, consider a Lee-Metford bullet moving with the normal speed of 1,800 feet per second. This projectile is 1 1/4 inches in length, it has a mass of about 0·03 lb., and it would be stopped in 1/18000 of a second. The force required to destroy the 1·7 lb.-second units of momentum would be 15 tons. Since the area of cross-section of the bullet is 1/14 of a square inch, the mean pressure would amount to 210 tons per square inch.

Passing over several interesting cases involving the propaga-

tion of longitudinal waves along steel rods, we shall now consider very briefly some entirely new investigations made by Hopkinson on the effects produced by detonating small cylinders of gun-cotton in contact with steel plates. The gun-cotton is converted into gas at small volume, high temperature, and enormous pressure, in roughly three or four millionths of a second. The only thing which restrains the expansion of the gas is the inertia of the surrounding air, and the pressure accordingly drops with very great rapidity. It is estimated that the pressure falls from 120 tons per square inch to atmospheric value in about 1/25000 of a second. The same pressure is, of course, exerted by the gas upon any rigid surface with which the gun-cotton is in contact, and the force so produced has the characteristics of a blow, namely, great intensity and short duration. If a cylinder of gun-cotton weighing one or two ounces is placed in contact with a plate of mild steel one half an inch thick, or less, and if the explosive is then detonated, the effect will be to punch a clean hole through the plate, of approximately the same diameter as that of the cylinder of gun-cotton, just as if a projectile had passed through the plate. On the other hand, if the steel plate had a thickness of three-quarters of an inch, a very curious result would be obtained. A depression would be formed on the side of the plate next to the explosive, while a disc of steel of corresponding diameter would be torn off from the opposite face of the plate and projected with very high speed. The speed, in fact, corresponds to a large fraction of the whole momentum of the blow. By detonating a two-ounce cylinder of gun-cotton in contact with a still thicker plate of steel, a depression and a complementary bulge were produced on the respective faces of the plate. When the plate was sawed in two in a plane containing the centers of the dent and of the lump, the presence of an internal crack was brought to light, thus showing the beginning of that separation which was complete in the case of the plate three-quarters of an inch thick. All of these phenomena can be accounted for by simple mechanical principles involving the reflection of longitudinal or sound waves in the metal.

In conclusion, a few words with regard to the behavior of large projectiles and armor-plate may not be without interest. Modern shells are made of a special steel of great strength and considerable ductility, the region of the point only being subsequently hardened by thermal treatment. When a shell of this construction strikes normally against a plate of wrought iron, or even mild steel, it ploughs straight through the plate, pushes a plug of metal before it, and emerges unscathed. A rim or lip is formed on the incidence face of the plate, which is analogous to the rim arising when a hole is blown in a lead plate by means of a gun-cotton primer. To bring a 14-inch shell, having a speed of 2,000 feet per second, to rest would require at least 2·5 feet of wrought iron. Modern armor plate is made as hard as possible on the outside surface, the back being left tough and ductile. When a

shell with a hard point is incident normally on such armor, both the projectile and the plate are seriously damaged, but the former does not penetrate the latter. Even when a thinner plate is pierced by the shell the projectile is usually smashed to pieces in the act. To overcome this lack of penetrating power it has become the custom, in recent years, to provide the point of the shell with a cap of soft steel. In this event, the projectile punches a clean hole both in its cap and through the armor plate. In some instances the shell is so nearly intact as to admit of its being used over again. The cap seems to form a ring around the nose of the shell at just the right instant, preventing any lateral deformation or flow of the tip, thus concentrating the blow over a small area and enabling the projectile to pierce the armor.—*Nature*, February 15, 1912, p. 531. H. S. U.

8. *A Photographic Study of Vortex Rings in Liquids.*—For purposes of demonstration, vortex rings are usually made in air by sending puffs of smoke through a circular opening in the front of a suitable box. It has been shown quite recently, however, by EDWIN F. NORTHRUP that more beautiful and instructive results can be obtained by using liquids of small viscosity instead of air. The essential parts of the apparatus used and a few of the phenomena produced may be briefly described as follows:

The rectangular experimental tank was chiefly made of plate glass and its length, depth, and width were respectively 151^{cm}, $59{\cdot}5^{cm}$, and 12^{cm}. The vortex rings were projected by means of a cylindrical can or "gun" $7{\cdot}7^{cm}$ in diameter and $6{\cdot}6^{cm}$ axial length. One end of this can consisted of a flexible diaphragm of phosphor bronze which could be given an impulse by the plunger of an electromagnet. The muzzle end of the gun was partly closed by any one of a set of metal discs which contained one or more holes of various shapes and dimensions. A circular hole 1^{cm} in diameter and at the center of the disc was usually employed to produce single vortex rings. To produce double rings two holes each of $0{\cdot}85^{cm}$ diameter were provided with their centers at a distance of $1{\cdot}275^{cm}$ from the axis of the cylinder. The tank was generally filled with slightly acidulated water whereas the can contained strongly alkaline water which was deeply colored with phenol phthaleïn. By this scheme the necessity of refilling the tank after one or two "shots" was avoided because the deep red vortex rings disappeared completely as soon as they lost their form and became dispersed.

Before investigating photographically the behavior of the rings, Northrup observed the following noteworthy properties of the vortices. The speed of the rings was initially about two meters per second and, when free to do so, they moved in straight lines with their planes perpendicular to the direction of propagation. They did not appropriate suspended particles of slightly greater density than the medium in which they moved. When a tightly-stretched sheet of chiffon cloth was interposed in the path of the vortex, the ring would pass through the net without being

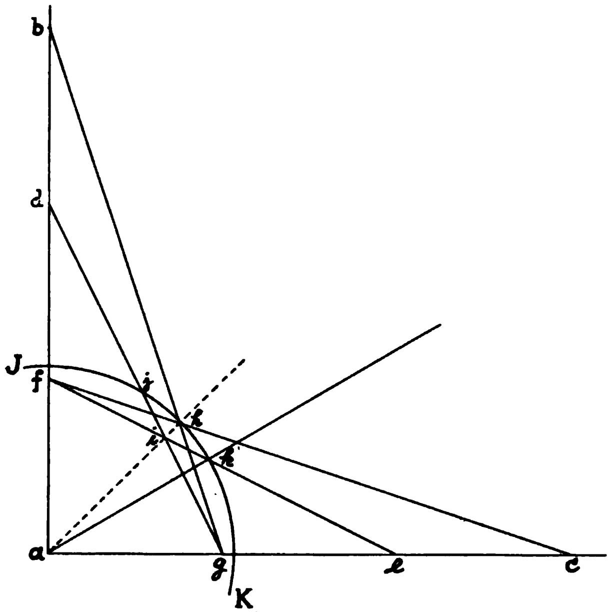
destroyed or greatly retarded. In fact, a ring would break through a sheet of tissue paper, but it would be scattered by the impact. Also, a light watch-chain would be bent into a decided curve by a square blow of a ring, hence the kinetic energy of the rings was quite appreciable. When two rings were sent simultaneously from opposite ends of the tank they would be destroyed if their lines of propagation coincided exactly, but they would separate and avoid one another if they were so aimed as to bring their edges into contact if the rectilinear motion persisted. Internal reflection at the free surface of the acidulated water took place in a beautiful manner when the angle of incidence exceeded about 68°. As the surface of the water was approached the upper edge of the ring would gain in speed as compared with the lower edge and the plane of the vortex would tilt in such a manner as to maintain itself always normal to the direction of propagation. For smaller angles of incidence than the critical angle the ring would burst through the surface with a spurt of water. Refraction was also shown by filling the lower half of the tank with a concentrated salt solution, and the upper half with pure water. Vortex rings issuing from a truly circular hole do not vibrate, but rings projected from an elliptical opening exhibit a vibratory motion in their own plane. These vibrations are very rapid and consist in changing from ellipses with vertical major axes to ellipses with the longer axis horizontal.

Most interesting results were obtained with two circular holes in the muzzle disc of the gun. "The two rings, which issue simultaneously from the two holes, begin to attract each other the moment they leave the gun, and at a distance from the gun of about 6 to 8^{cm} they come together with great suddenness, uniting to form a single ring of approximately twice the circumference of one of them." The rings thus formed proceed with the same speed as a single ring, but the vibratory motions are rather complicated. The component vibrations can only be fully appreciated by reference to the reproductions of the stereoscopic photographs in which the original paper abounds.

Experiments were performed which showed that, in the case of two non-miscible liquids of different densities, it is possible to project a vortex of the less dense liquid through the medium of greater density, but it is not possible to reverse the process. For example, a ring of kerosene oil can be projected through water, but a vortex of carbon tetrachloride cannot. By projecting rings of liquid paraffin through hot water and thence into a substratum of cold water, very pretty *solid rings of paraffin were obtained and preserved.*

The difficulties attendant upon photographing the vibrating rings were comparatively great and the requisite assemblage of apparatus was too complicated to admit of description in this place. Suffice it to say that full details of the experimental processes together with a relatively large number of photographic reproductions are given in the September and October numbers (1911) of the Journal of the Franklin Institute.—*Nature*, February 1, 1912, p. 463. H. S. U.

9. *Note on Nevil Maskelyne's Article, "On the Trisection of an Angle";* by H. S. UHLER (communicated).—In the Philosophical Magazine for April, 1912, a geometrical construction is given by Maskelyne, on page 647, which he states will trisect any angle. This claim is surprising because the construction is not qualified as an approximation and also because no proof is suggested in the article. It is the purpose of the writer to show that the aforesaid construction is not valid. To accomplish this, it is sufficient to prove that a right angle will not be trisected in the manner indicated by Maskelyne.



In the accompanying figure the letters have the same significance as in the original article.

Let $= \overline{af} = \overline{fd} = \overline{db} = \overline{ag} = \overline{ge} = \overline{ec} = 1.$

From the right triangle caf, $\overline{cf} = \sqrt{10}$.

Since $\overline{ah}$ bisects $\angle cab$, $ch = \frac{3}{4}\,\overline{cf} = \frac{3}{4}\sqrt{10}$.

$\overline{ah}^2 = \overline{ac}^2 + \overline{ch}^2 - 2\,\overline{ac}.\,\overline{ch}.\,\cos\,(\angle acf) = \frac{9}{8} = \overline{ak}^2.$

Considering $\overline{ac}$ and $\overline{ab}$ as axes of x and y respectively, it follows that the equation of the line $\overline{ef}$ is $x + 2y - 2 = 0$, and of the circle $\overline{JK}$, $8x^2 + 8y^2 - 9 = 0$. Consequently the coördinates of k are $\left(\frac{\sqrt{26}+4}{10}, \frac{16-\sqrt{26}}{20}\right)$.

Hence, $\tan(\angle cak) = \dfrac{16-\sqrt{26}}{2\sqrt{26}+8} = \sqrt{26} - 4{\cdot}5 \doteqdot 0{\cdot}599019$

and $\angle cak \doteqdot 30° \ 55' \ 21''$.

Therefore, in this special case, the error amounts to nearly one degree. It may be remarked, in conclusion, that we have worked out an analytical expression, *for the general case*, connecting $\angle cak$ with $\angle cab$ and found that this function is not satisfied by putting $\angle cab = 3(\angle cak)$.

II. Geology.

1. *Publications of the United States Geological Survey;* George Otis Smith, Director.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from p. 62, Jan., 1912):

Topographic Atlas.—Sixty-five sheets.

Folios.—No. 178. Foxburg–Clarion Folio, Pennsylvania; by E. W. Shaw and J. M. Munn. Pp. 17; columnar section, 4 topographic and geologic maps.

No. 179. Pawpaw–Hancock Folio. Maryland–West Virginia–Pennsylvania; by George W. Stose and Charles K. Swartz. Pp. 24; 3 topographic and geologic maps; 20 half tone views.

No. 180. Claysville Folio, Pennsylvania; by M. J. Munn. Pp. 14; sections, 4 topographic and geologic maps. 10 figures.

No. 181. Bismarck Folio, North Dakota; by A. G. Leonard. Pp. 8; 1 topographic, 1 geologic map.

Mineral Resources of the United States. Calendar year 1910. Part I.—Metals. Pp. 796; 1 plate, 9 figures. Part II.—Nonmetals. Pp. 1005; 17 plates, 10 figures. The individual chapters of this invaluable compilation have already been issued in advance.

Bulletins.—No. 470. Contributions to Economic Geology (Short Papers and Preliminary Reports), 1910. Part I.—Metals and Nonmetals except Fuels. C. W. Hayes and Waldemar Lindgren, Geologists in Charge. Pp. 558; 17 plates, 64 figures.

No. 485. A Geologic Reconnaissance of the Iliamna Region, Alaska; by G. C. Martin and F. J. Katz. Pp. 138; 9 plates, 20 figures.

No. 493. Results of Spirit Leveling in Illinois, 1909, 1910; R. B. Marshall, Chief Geographer. Pp. 115; 1 plate.

No. 494. The New Madrid Earthquake; by Myron L. Fuller. Pp. 119; 10 plates, 18 figures.

No 496. Results of Triangulation and Primary Traverse for the Years 1909 and 1910. R. B. Marshall. Chief Geographer. Pp. 392; 2 plates.

No. 497. A Reconnaissance of the Jarbridge, Contact, and Elk Mountain Mining Districts, Elko County, Nevada; by F. C. Schrader. Pp. 162; 26 plates, 3 figures.

No. 499. Coal Near the Black Hills, Wyoming–South Dakota; by R. W. STONE. Pp. 66; 7 plates, 8 figures.

No. 500. Geology and Coal Fields of the Lower Matanuska Valley, Alaska; by G. C. MARTIN and F. J. KATZ. Pp. 98; 19 plates, 12 figures.

No. 504. The Sitka Mining District, Alaska; by ADOLPH KNOPF. Pp. 32; 1 plate, 4 figures.

No. 505. Mining Laws of Australia and New Zealand; by ARTHUR C. VEATCH with a preface by WALTER L. FISHER. Pp. 180.

No. 511. Alunite: a newly discovered deposit near Marysvale, Utah; by B. S. BUTLER and H. S. GALE. Pp. 64; 3 plates. This new locality for alunite gives promise of affording a considerable amount of the potash so much needed in this country.

WATER-SUPPLY PAPERS.—No. 280. Gaging Stations maintained by the U. S. Geological Survey, 1888–1910, and Survey Publications relating to Water Resources; compiled by B. D. WOOD. Pp. 102.

Nos. 282, 286, 287. Surface Water Supply of the United States, 1910; prepared under the direction of M. O. LEIGHTON. No. 282. Part II. South Atlantic Coast and Eastern Gulf of Mexico; by M. R. HALL and J. G. MATHERS. Pp. 109; 3 plates. No. 286. Part VI. Missouri River Basin; by W. A. LAMB, W. B. FREEMAN, RAYMOND RICHARDS, and R. C. RICE. Pp. vii, 308; 4 plates, 1 figure. No. 287. Part VII. Lower Mississippi Basin; by W. B. FREEMAN and J. G. MATHERS. Pp. 91; 2 plates.

2. *Cambro-Ordovician Boundary in British Columbia with description of fossils;* by CHARLES D. WALCOTT. Smithsonian Misc. Col., 57, No. 7, pp. 229–237, pl. 35, 1912.—Until now the boundary between the Cambrian and Ordovician of America has not been clearly established on paleontologic evidence. Due to the discovery of fossils by J. A. Allan of the Geological Survey of Canada, and later by L. D. Burling, Walcott is now able to indicate this division with certainty for the Rocky Mountain region. Some time ago he placed the line at the top of the Sherbrooke formation which has in its upper beds *Lingulella isse* and a Ptychoparia, fossils indicating the Upper Cambrian. This formation is now known to be followed by the Chancellor, about 2500 feet thick, then the Ottertail blue limestone with a thickness of 1550+ feet. The latter yields *Lingulella* cf. *isse*, Agnostus, and Ptychoparia, fossils indicating Cambrian time.

Above the Ottertail formation appear interbedded cherts, cherty limestones, dolomitic limestones and siliceous and calcareous slates and shales over 6000 feet in thickness, referred to the Goodsir formation. In the lower part Allan found the new species here described by Walcott as *Obolus mollisonensis*, *Lingulella? allani*, *L. moosensis* and *Ceratopyge canadensis.*

"The discovery of fairly well characterized specimens of the trilobitic genus *Ceratopyge* associated with brachiopods of the same general type as those found in the *Ceratopyge* shale of

Sweden is most important, as it gives the first definite suggestion of a base for the Ordovician in the section along the Canadian Pacific Railway west of the Continental Divide. In Sweden the *Ceratopyge* shale and limestone are now by general assent placed at the base of the Ordovician, and with our knowledge of the stratigraphy of the upper portion of this section as determined by Mr. Allan I am inclined to agree with him in placing, at least tentatively, the boundary between the Cambrian and Ordovician at the summit of the Ottertail limestone and the base of the Goodsir formation" (230). C. S.

3. *The Sardinian Cambrian Genus Olenopsis in America;* by CHARLES D. WALCOTT. Smithsonian Misc. Col., 57, No. 8, pp. 239–249, pl. 36, 1912.—The author here describes three species of Olenopsis derived from the upper part of the Lower Cambrian of Pennsylvania and from the passage beds at the base of the Middle Cambrian in Montana, Alberta, and British Columbia. The genus was originally discovered in Sardinia, where its exact stratigraphic position remained undetermined. Walcott shows in this paper that the Sardinian species probably is of the time of the strata "beneath the Middle Cambrian *Paradoxides* beds, either in passage beds from the Lower to the Middle Cambrian, or in the upper beds of the Lower Cambrian" (239). C. S.

4. *Middle Cambrian Branchiopoda, Malacostraca, Trilobita, and Merostomata;* by CHARLES D. WALCOTT. Smithsonian Misc. Col., 57, pp. 148–228, pls. 24–34, 1912.—In this preliminary paper of extraordinary interest are described 1 new order, 5 new families, 5 old and 19 new genera (of Branchiopoda, *Opabinia*, *Leanchoilia*, *Yohoia*, *Bidentia*, *Naraoia*, *Burgessia*, and *Waptia;* of Malacostraca, *Hurdia*, *Tuzoia*, *Odaraia*, *Fieldia*, and *Carnarvonia;* of trilobites, *Marrella*, *Nathorstia*, *Mollisonia*, and *Tontoia;* of Merostomata, *Molaria*, *Habelia*, and *Emeraldella*), and 31 new species. Nearly all are derived from the Burgess shale of Middle Cambrian age near Field, British Columbia. This shale has furnished the author with no less than 56 genera derived from a block of shale not over 6 by 40 feet in area and 7 feet in thickness. No other locality has given us such an astonishing insight not only into the life of the Middle Cambrian but as well into what must have been the stage and diversity of invertebrate life in pre-Cambrian time. Nevertheless the Burgess shale record is said to be imperfect for "We have only a portion of a crustacean fauna that was already developed early in Cambrian time" (153).

Students of trilobites will be much interested to know that these animals (certainly at least Neolenus) had a pair of long jointed caudal rami that are not unlike those in Apus. On the other hand Marrella is a trilobite suggesting Apus in its long and tapering abdomen.

Walcott states that these Middle Cambrian Branchiopoda and Malacostraca have normally 6 pairs of cephalic appendages, if the

stalked eyes are regarded as representing the first pair. These "are not very unlike those of recent crustaceans of the same orders," while the thoracic appendages appear to be based on the typical crustacean biramose limb.

The author thinks it probable that the Branchiopoda, Malacostraca, Ostracoda, Trilobita, and Merostomata had their origin previous to the Cambrian. In regard to Bernard's interesting theory that Apus was developed out of a "browsing carnivorous annelid with its first 5 segments (head) bent so that its mouth faced ventrally and posteriorly," Walcott "examined the Burgess shale annelidan and crustacean fauna to ascertain if there was an annelid that could be considered as representing his hypothetical crustacean annelid, and nearer to it in structure than Apus. I found specimens of *Canadia spinosa* Walcott laterally flattened in the shale with the head bent down, so that the mouth faces posteriorly (Smiths. Misc. Col., 57, No. 5, 1911, pl. 23, fig. 4), also that 14 out of 24 specimens have the head bent under and out of sight beneath the flattened body. Possibly these annelids and the crustaceans were derived from the same general type of animal" (162).

"As to the relations of the Branchiopoda, Leptostraca (representing the Malacostraca), Trilobita, and Merostomata the inter-relationship of the four so-called subclasses is found to be very intimate. In *Opabinia* and *Leanchoilia* the typical branchiopod is clearly present. In *Waptia* the Leptostraca is very near at hand as developed in *Hymenocaris.*

"In *Marrella* the trilobite is foreshadowed, and *Nathorstia* is a generalized trilobite as the trilobite appears to be a specialized branchiopod, adapted largely for creeping on the bottom. The trilobite gives some conception of a possible form between the Branchiopoda and the Aglaspidæ of the Merostomata" (163).

From the Apodidæ "it is assumed that the Branchiopoda came, and from the Branchiopoda stock three distinct branches were developed prior to or during Cambrian time." In one line of descent "it is assumed that the Trilobita are directly descendent from the Branchiopoda and forms grouped under the order Aglaspina derived from the Trilobita. The order Limulava is considered as being intermediate between Aglaspina and the Eurypterida, and that the two orders Limulava and Aglaspina serve to connect the Trilobita and the Eurypterida.

"From the Eurypterida we pass to the Xiphosura. It is thought that the Phyllocarida, as represented by the group of forms included under the Hymenocarina, came from the Branchiopoda, but on a different line of descent from the Trilobita and the orders grouped under the Merostomata.

"The ostracods are assumed to have been derived from the Branchiopoda, but on a different line of descent from the Trilobita and Phyllocarida" (163-4). C. S.

5. *Strophomena and other fossils from Cincinnatian and Mohawkian horizons, chiefly in Ohio, Indiana, and Kentucky ;*

by AUG. F. FOERSTE. Bull. Sci. Lab., Denison Univ., xvii, pp. 17–174, pls. i–xviii, 1912.—The greater part of this work is devoted to detailed descriptions of 41 species (9 new) of brachiopods and 2 other new fossil forms. Throughout the descriptions and on the introductory pages is presented an immense amount of stratigraphic detail along with the geographic distribution of the species discussed. On page 23 is a revised table of the Cincinnatian and Mohawkian formations embracing no fewer than 50 stratigraphic subdivisions. In the last paragraph (page 139) the author makes three generic changes affecting brachiopod genera proposed by him in 1909, but the reasons for the substitutions are not stated. These are *Schizoramma* for Schizonema, *Pionodema* for Bathycœlia, and *Encuclodema* for Cyclocœlia. C. S.

6. *The Arnheim formation within the areas traversed by the Cincinnati geanticline;* by AUG. F. FOERSTE. Ohio Naturalist, xii, No. 3, pp. 429–453, pls. xx–xxii, 1912.—The Arnheim formation is in the upper part of the Ordovician and at the base of the Richmond series. Its distribution in Kentucky, Indiana, and Ohio is here described. It is in this formation that the Richmond faunas make their appearance, but the source whence this migration came the author does not state, though he seems to favor an entrance from the southwest toward the northeast. The Arnheim is also a time of crustal warping and the breaking down of some unknown barrier, permitting the introduction of the Richmond fauna. C. S.

7. *Paleontologia Universalis*, ser. 3, fasc. 3, July, 1911.—This recently published fasciculus of reproductions and emendations of poorly understood invertebrate species (1821–1850) treats of 25 forms recorded on 56 sheets. C. S.

8. *Petrographic Methods.* Translated from the German of E. WEINSCHENK by R. W. CLARK. 8°, pp. 396, figs. 371. New York, 1912 (McGraw-Hill Co.).—No more convincing evidence of the fact that petrology has become a definite science, which occupies a field of its own, can be found than in the appearance of volumes devoted to a description and discussion of its technical methods, such as the one before us, and that noticed in the following review. This work of Professor Weinschenk has now been used for several years in the original, and has met in German-speaking countries with very favorable consideration in the field for which it was designed. It does not aim at the comprehensive and mathematical treatment of subjects which characterizes the great work of Rosenbusch and Wülfing, but seeks in simpler form, and mostly without mathematical discussion, to convey to the student the essential principles which underlie the optical study, investigation, and determination of crystalline substances. This is accomplished by careful and extended explanations and description of apparatus and of the proper methods of its use. The form of presentation of the matter is, therefore, not merely synoptic of a larger work, as is too often the case in manuals which are designedly somewhat elementary in character, but rather full, so far as the field is covered.

The second part of the work is devoted to a description of the rock-making minerals. In this the matter is considerably condensed to bring it within the limits of the work. The essential material only is given and the subject matter of the less common, or less important species, is more condensed by use of smaller type. A set of tables, such as are found in most of the well-known texts, concludes the work.

The translator has done his part of the work carefully and well. The book is well printed and attractively bound, and is illustrated by numerous diagrams, cuts, and half tones, which add greatly to the understanding of the text. While the work will not replace the more comprehensive manuals, which are necessary to the advanced students and teachers of petrography, it will, without doubt, find a very useful field of its own with beginners and with those who desire a simpler method of treatment of the subject matter. L. V. P.

9. *The Methods of Petrographic-Microscopic Research;* by FRED. EUGENE WRIGHT. 8°, pp. 204, 11 plates, 118 figures, 1912. Carnegie Institution, Washington.—This work is almost the antithesis of the one noticed above. Its intent is seen in the subtitle, which reads "Their relative accuracy and range of application." It is probably the most serious, scholarly and generally comprehensive investigation of the optical methods employed in petrographic research, to the extent indicated in the sub-title, which has yet appeared, and it cannot fail to have a great influence in promoting more careful and thorough work along these lines. It is in no sense a text-book, and is no work for beginners, but it is one which should be in the hands of every teacher and advanced worker in petrography. It begins with an investigation of the microscope, which is thoroughly discussed as an instrument of precision in optical research. After this various subjects, such as color, pleochroism, optical characters of birefracting substances, refractive indices, birefringence and its measurement, extinction angles, optic axial angles, etc., are treated in successive chapters. The various methods and apparatus invented in recent years, largely by the author, in the Geophysical Laboratory of the Carnegie Institution, are for the most part usefully included. A series of carefully constructed plates, using various modes of projection, furnish, by graphic methods, quick and easy solutions of problems of determination, as, for instance, to reduce the optic angle observed in air to be the true angle in the substance, when the index of refraction is known.

It is work of this character, the result of careful, accurate, intelligent and highly trained effort directed to a particular field of science, that makes the productions of the institution which produces them of such a high degree of merit. L. V. P.

10. *The Soil Solution: The nutrient medium for plant growth;* by FRANK K. CAMERON. Pp. iv, 125, with Index and 3 ills. Easton, Pa., 1911 (The Chemical Publishing Co.).—For some years the Soil Survey at Washington has been engaged, among

other things, in a careful study of the chemistry of soils. The result has been a large number of valuable quantitative determinations that have cleared up many points concerning soil fertility, and have indicated the lines which many of the later investigations should follow. The main results of these Government studies have been organized in an attractive manner and presented by the chemist in charge in the form of a book as above. A few chapters, such as "The Mineral Constituents of the Soil Solution," and "The Organic Constituents of the Soil Solution," are here presented practically as they appeared in Government Bulletins, except that a large number of relatively unimportant citations have been omitted. The organization of these and other chapters with reference to each other has been carefully done, so that the work is a unit. In addition, a preliminary chapter on The Soil, others on Soil Management, Soil Water, Fertilizers and Alkali, make the book a well-rounded treatise on soils from the chemical standpoint. I. B.

III. Miscellaneous Scientific Intelligence.

1. *National Academy of Sciences.*—The annual spring meeting of the National Academy of Sciences was held in Washington on April 16–18; some forty-five members were present.

The following gentlemen were elected to membership in the Academy: John Jacob Abel, Johns Hopkins University; Charles Benedict Davenport, Station for Experimental Evolution, Cold Spring Harbor, N. Y.; Samuel James Meltzer, Rockefeller Institute for Medical Research, New York; Harry Fielding Reid, Johns Hopkins University; Roland Thaxter, Harvard University; William Morton Wheeler, Harvard University; David White, U. S. Geological Survey, Washington, D. C., and Robert Williams Wood, Johns Hopkins University.

Sir John Murray was elected a foreign associate of the Academy.

The following is a list of the papers presented at the meeting:

George E. Hale: The new tower telescope of the Mount Wilson Solar Observatory.

W. W. Campbell: Radial velocities of 218 brighter Class A stars. Radial velocities of 190 brighter Class F stars. Some characteristics of stellar motions.

W. J. Humphreys: Holes in the air.

R. A. Harper: The organization of the cell colony in Pediastrum.

D. H. Campbell: On the morphology and systematic position of *Calycularia radiculosa* (Sande Lac) Stephens.

William Trelease: A revision of Phoradendron.

H. F. Osborn: Biological Foundation of Bergson's "Creative Evolution."

Harvey Cushing: Some observations on the functions of the pituitary body.

Jacques Loeb: The activation of the animal egg from the physico-chemical standpoint.

J. A. Holmes: The national phases of the mining industry.

C. G. Abbot: The solar radiation.

E. S. Morse: Biographical memoir of C. O. Whitman.

G. L. Goodale: Biographical memoir of Alexander Agassiz.

2. *The Carnegie Foundation for the Advancement of Teaching. Sixth Annual Report of the President*, HENRY S. PRITCHETT, *and of the Treasurer*, ROBERT A. FRANKS. Pp. vi, 154. New York City, October, 1911.—The total fund now in the hands of the Trustees of the Carnegie Foundation amounts to something more than $12,000,000, giving an income for the past year of $590,500. Of this latter sum, all but about $10,000 was expended, most of it for retiring allowances and pensions to teachers and their widows; less than $54,000 was needed for administrative expenses. The fact that income and expenditure are now so closely balanced gives emphasis to the discussion by the President in this report as to the general subject of college pensions. In his judgment they should carry with them, as is true of many similar funds, a contributory feature. He urges, also, that inasmuch as the Foundation can in the future care for only a small fraction of the college teachers in America, it is the duty of each college to mature plans for assuming its own obligations in this direction. It is to be noted that of the additional gift of $5,000,000 promised by Mr. Carnegie in March, 1908, the first installment of $1,000,000 was paid in March a year ago. The total number of institutions now on the accepted list is seventy-two, the University of Virginia having been added during the current year.

The present volume contains, in its second part (pp. 45–123), a considerable number of chapters by the President, dealing with the vital general problems in which the universities and the professional schools of the country are concerned. He notes a remarkable development in the educational movement in the United States as shown in the increase of students, the adjustment of the college to the four-year high school, and the increase of the number of secondary schools of the four-year type. He sees also a gratifying progress in the various lines of professional work and in the movement of State institutions towards educational and political freedom.

3. *Report of Superintendent of the Coast and Geodetic Survey*, O. H. TITTMANN, *showing the Progress of the Work from July 1, 1910, to June 30, 1911.* Pp. 584; 9 pocket maps. Washington, 1912.—The annual volume from the Coast and Geodetic Survey gives the usual interesting summary, by the superintendent, of the work done in the country and the outlying territories. To be noticed is a reconnaissance for primary triangulation to extend from the 39th parallel triangulation near Colorado Springs to the Canadian boundary. This was begun in May and, at the end of the year, four hundred miles of progress had been made. It is also stated that the Texas–California arc of primary triangulation from Texas to the Pacific coast, connecting the 98th meridian triangulation with that in the vicinity of San Diego, was completed during the year. Progress has also been made in the surveying and marking of the boundary lines between the United States and Canada. Of the six Appendixes accompanying the volume are to be mentioned: one on the magnetic observations of the Survey, by R. L. Faris; on triangulation along the

98th meridian, Nebraska to Canada and Duluth, by William Bowie, and on the same meridian, Seguin to Point Isabel, Texas, by A. L. Baldwin; on triangulation along the east coast of Florida and the Keys, by H. C. Mitchell.

4. *Bulletin of the Bureau of Standards;* S. W. STRATTON, Director.—The first number of volume VIII, Jan. 1912, is devoted to a paper of 237 pages, by EDWARD B. ROSA and F. W. GROVER, containing formulas and tables for the calculation of mutual and self-inductance (revised).

The following important technologic papers have also been issued by the Bureau of Standards:

No. 2. The Strength of reinforced Concrete Beams; Results of Tests of 333 Beams (first series); by R. L. HUMPHREY and LOUIS H. LOSSE. Pp. 200; 45 figures.

No. 3. Tests of the absorptive and permeable Properties of Portland Cement Mortars and Concretes, together with Tests of damp-proofing and water-proofing Compounds and Materials; by RUDOLPH J. WIG and P. H. BATES. Pp. 127; 53 figures.

No. 5. The Effect of high pressure Steam on the crushing Strength of Portland Cement, Mortar, and Concrete; by RUDOLPH J. WIG. Pp. 25.

OBITUARY.

RALPH STOCKMAN TARR, Professor of Physical Geography in Cornell University, died suddenly, after a brief illness, on March 21st at the age of forty-eight.

He was born at Gloucester, Mass., Jan. 15th, 1864, and early showed a bent for natural history studies. After a brief period of study in the Summer School of Zoology at Salem, Mass., in the fall of 1881 he entered the zoological laboratory of Alpheus Hyatt, acting as his assistant for two years. He took part in the deep-sea explorations of the "Fish Hawk" and "Albatross" sent out by the U. S. Fish Commission in 1883; assisted Professor Shaler in the field work on the Geology of Cape Ann; and in the year 1889 was assistant on the Texas Geological Survey. While engaged in these various modes of practical scientific work in science he was registered as a student at Harvard, graduating from the Lawrence Scientific School with the degree of B.S. in 1891. In 1892 he was appointed Assistant Professor of Dynamic Geology and Physical Geography in Cornell University and Professor of Physical Geography in 1906, the position he held at the time of his death.

In addition to excursions and explorations in and about Ithaca, New York state, carried on both for training of his classes in physiography and as research, he made more extended researches in Alaska and Greenland, chiefly studying glaciers, and spent the years 1901–2 and 1909–10 in Europe studying similar problems.

Professor Tarr wrote several text-books on Physical Geography, the latest of which, "A Laboratory Manual of Physical Geography" by R. S. Tarr and O. D. VanEngeln, was published in

1910. He also prepared a beautifully illustrated "Monograph o the Yakutat Bay Region, Alaska, Physiography and Glaci Geology" which was published in 1909 as Professional Pape No. 64 of the U. S. Geological Survey. He assisted in the prepa ration of the "Watkins Glen–Catatonk Folio" (published th same year by the Survey) comprising the area of two 15-minute quadrangles immediately surrounding Ithaca and Cornell University. Among his published papers are also numerous contributions to scientific and educational journals.

He was vigorously at work up to a few days of his death. The correcting of proof-sheets of a Professional Paper for the U. S. Geological Survey on "Alaskan earthquakes" and the writing of a text-book on "Advanced Physiography" were brought to a close by his death. During the past winter he had been actively engaged experimenting upon glacier and pond-ice, seeking evidence of the determining causes and conditions of the motion of glaciers. Dr. O. D. VanEngeln was assisting him in these experiments and will continue them and prepare the record of the experiments for publication. A scientific account of his four expeditions to Alaska to study its glaciers had but recently been finished. Professor Lawrence Martin was associated with him in its preparation and will complete it for publication. He was also looking eagerly forward to making further explorations in Newfoundland during the coming summer when his life was suddenly terminated. Professor Tarr was one of the first American teachers to give university rank to the physical geography of the high school curriculum. His training under Davis at Harvard specially fitted him for the task and at Cornell he found the opportunity to build up a well-equipped physiographic laboratory for the scientific teaching and investigation of the problems of physiography. He was a vigorous explorer, a keen observer, a ready speaker, an interesting and inspiring teacher and will be greatly missed not only by his many pupils but by physiographers at home and abroad, among whom he had already attained high rank. He was President of the Association of American Geographers, foreign correspondent of the Geological Society of London, fellow of the Geological Society of America and member of other scientific and educational societies; and associate editor of the Journal of Geography and of the "Bulletin" of the American Geographical Society and corresponding member of La Commission Internationale des Glaciers. H. S. W.

Professor A. Lawrence Rotch, the meteorologist, died on April 7 at the age of fifty-one years. In 1885 he established and subsequently maintained the Blue Hill Meteorological Observatory. He was the first to use kites in the recording of the meteorological data of the upper atmosphere, and through this work, his investigation of clouds and in other similar lines, his contributions to science were numerous and important.

Professor Osborne Reynolds, distinguished for his important contributions to engineering and theoretical physics, died on February 21 at the age of seventy years.

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ART. XLIII.—*The Nitrogen Thermometer Scale from 300° to 630°, with a Direct Determination of the Boiling Point of Sulphur;* by ARTHUR L. DAY and ROBERT B. SOSMAN.

1. *Purpose and Plan of the Investigation.*

IN our recent investigation of the fundamental high temperature scale with the gas thermometer,* attention was chiefly directed to the temperature region above 1000°. The lower temperatures had been determined with considerable accuracy in an investigation undertaken in the Reichsanstalt† some years earlier (1900) and there was no reason to suspect any uncertainty in it of greater magnitude than the errors of observation determined at that time (2° to 3°). This does not mean that it was considered unnecessary to reduce the magnitude of the errors, which were known or suspected to exist in the Reichsanstalt instrument,—quite the contrary. All our efforts throughout an investigation which has now continued since 1904 have been put forth in the direction of reducing these errors to a minimum, but this was done more especially because of their much greater influence upon temperature determinations above 1000° than because of any specific demand which then existed for a new or better temperature scale in the region below that temperature.

The situation from our viewpoint at the time of publication

* Preliminary Publications:
  Day and Clement, Phys. Rev., xxiv, 531, 1907 (Abstract).
  Day and Clement, this Journal (4), xxvi, 405–463, 1908.
  Day and Sosman, " (4), xxix, 93–161, 1910.
  R. B. Sosman, " (4), xxx, 1–15, 1910.
Final Publication:
  Day and Sosman, Carnegie Institution Pub. No. 157, 1911.

† Holborn and Day, Ann. Physik (4), ii, 505–545, 1900; this Journal (4), x, 171–206, 1900.

of our final results (1911) was accurately summed up in one of our closing paragraphs as follows:

"The chief source of present uncertainty [in high-temperature gas-thermometer measurements] is the temperature distribution over the surface of the bulb in an air bath. It would be possible to eliminate this error in the lower portion of the scale by substituting a liquid bath which could be stirred. In fact, this was done for temperatures below 500° in the earlier work of Holborn and Day, but has not, so far, been tried in the present investigation because of the relatively secondary importance of the lower temperatures to the ultimate purpose of the investigation (the study of silicates). For the higher temperatures, no satisfactory liquid bath has been found."* (Publication of the Carnegie Institution No. 157, p. 125, 1911.)

The lower temperatures upon this scale, determined in an air bath, come out about 1° lower than the corresponding temperatures of the Reichsanstalt scale (determined in a liquid bath). These temperatures are compared below:

	Holborn and Day 1900	Day and Sosman 1911
Cadmium (melting point)....	321·7°	320·0°
Zinc " "	419·0	418·2
Antimony " "	630·6	629·2

This circumstance was the more conspicuous, and perhaps the more open to suspicion, because a discrepancy of precisely the same order of magnitude (1°) had appeared between air-bath and liquid-bath determinations in the neighborhood of 400° in the work of Holborn and Day in 1900, which eventually led them to reject the measurements made at that temperature in the air bath. It is, therefore, not surprising that the reappearance of this discrepancy should attract considerable attention even though this difference of 1° is within the stated and admitted limits of accuracy of the Reichsanstalt scale (2° to 3°). It is also serving a useful purpose in directing attention to an uncertainty which had remained undisturbed for so long that it probably had been forgotten, for there is abundant reason to believe that to-day, with a modern gas thermometer, adjusted to give appropriate sensitiveness, these temperatures can be determined with much greater accuracy than 1°.

That the Reichsanstalt is also of this opinion is shown by the recent publication of a new series of measurements† of these

* Prof. Holborn has directed attention to the same limitations in our results at these temperatures, in a recent paper, to which further reference will be made presently.

† Holborn and Henning, Ann. Physik (4), xxxv, 761-774, 1911.

temperatures. The gas thermometer measurements were made in a liquid bath, using a sensitive resistance thermometer to transfer the temperature from the bath containing the gas thermometer bulb to the (independent) sulphur boiling point apparatus. The lower temperatures were then interpolated by means of the platinum resistance thermometer. The new determinations were published so recently that there has been no opportunity for confirmation by other experimenters, but they appear to be free from any error greater than one or two tenths of a degree, and therefore indicate a very considerable increase in the accuracy of the results when compared with the earlier (1900) scale which is now in general use. Holborn and Henning's new results, on the thermodynamic scale, are in part as follows:

Benzophenone (boiling point).....	305·89°
Cadmium (melting point).........	320·92
Zinc " "	419·40
Sulphur (boiling point)...........	444·51

In certain studies* now under way in this laboratory on the effect of pressure upon equilibria greater accuracy is now required in the measurement of these particular temperatures than had previously been necessary. We therefore determined to repeat these measurements, with more elaborate precautions to secure a uniform temperature about the bulb, this being, as stated above, the one factor in our measurements about which some uncertainty remained. At any rate it was important to establish the identity and the magnitude of the error in the earlier measurements which may have been due to this cause.

2. *Apparatus.*

No attempt will be made to describe in detail the gas thermometer and accessories used in this investigation. A full description of the apparatus, with illustrations, will be found in the publications to which reference has been made. No change whatever was made in the gas thermometer system for these measurements, except for the substitution, about the bulb, of a liquid bath, made up from potassium and sodium nitrates in eutectic proportions (55 per cent KNO_3, 45 per cent $NaNO_3$). This bath was introduced into the furnace bomb described in connection with the earlier apparatus in place of the platinum wire furnace previously used. The insulating material was dried magnesia powder, as heretofore, and the bomb was water-jacketed throughout to protect the manometer. The general appearance of the furnace is shown by the accompanying diagram (fig. 1).

* Johnston and Adams, this Journal, xxxi, 501–517, 1911.

The vessel which contained the nitrates consisted of a cylindrical wrought iron tank 152^{mm} in inside diameter and of 7^{mm} wall thickness, into which the bottom plate was welded with an oxy-acetylene flame. This detail is perhaps worth some emphasis, because it was the only tank of three which were made up with various joints in the bottom which proved able to hold the nitrates up to a temperature of 630° without leaking.

Fig. 1.

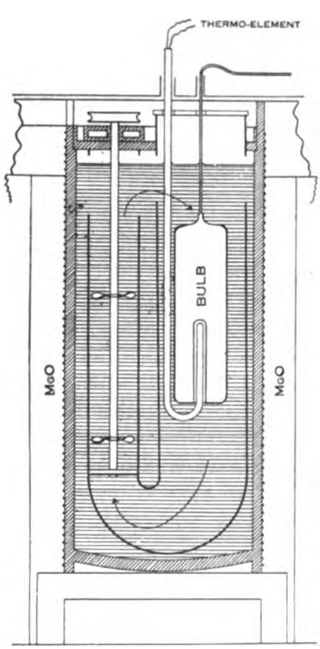

Fig. 2.

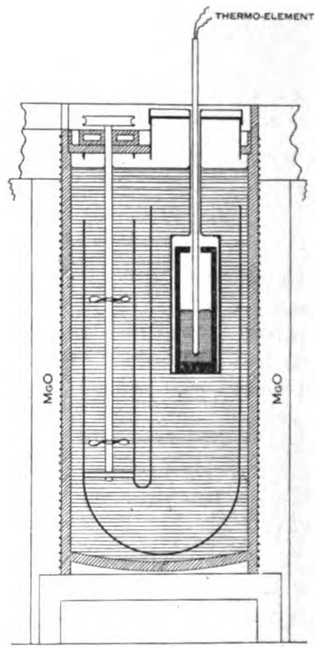

Fig. 1. Nitrogen-thermometer bulb in double nitrate bath. (The two thermoelements on the outside of the bulb are not shown.)

Fig. 2. Apparatus for the determination of the melting point of zinc in the nitrogen thermometer nitrate bath.

Scale: 1 to 6·5.

As at first used this tank was merely a covered vessel without partitions into which a turbine stirrer, operated by an electric motor, was inserted. The comparatively loose lower bearing of the turbine was lubricated by the liquid itself, the upper one was water-cooled. Alongside of this stirrer, and 30^{mm} distant from it in the bath, was the bulb of the gas thermometer. Although the stirring in the tank was vigorous, temperature differences amounting to 0·4° appeared between the top and the bottom of the bulb at 400°. The current in the liquid was up-

ward in the turbine tube and downward past the bulb. With this arrangement the top of the bulb was cooler.

In an air bath it had not proved possible to reduce the variation of temperature over the surface of the bulb below 1°, so that the liquid bath, even in this form, was an improvement over the air bath. But still greater uniformity was desired. After some experimenting, which need not be described here, the arrangement shown in the diagram (fig. 1) was adopted. It amounted, briefly, to one bath within another; that is, the tube containing the stirrer was continued across the bottom of the tank and upward about the bulb, which it fitted with but little clearance (10^{mm}) in order to insure the very rapid circulation of a thin layer of liquid past the bulb, while the remainder of the bath remained at an approximately uniform temperature without. With this arrangement no systematic temperature differences greater than the errors of observation of the thermoelements (0·1°) were observed.

3. *Method of Procedure.*

In this apparatus temperatures were read simultaneously (1) upon the gas thermometer, (2) upon three thermoelements distributed at different points in the bath,—one in a re-entrant tube extending to the center of the bulb, and one each at the top and bottom of the outside wall.

For the measurements at the benzophenone boiling-point thermoelements of copper-constantan and of platinum-platinrhodium (Heraeus) were used, for the higher temperatures platinum-platinrhodium only. After a trial of the copper-constantan elements at the next higher temperature (zinc), evidence of permanent changes in their readings was obtained which was more than sufficient to offset their increased sensitiveness. They were accordingly abandoned in work at the higher temperatures.

A thermoelement suggested by Geibel,* of gold against an alloy of 60 gold, 40 palladium, was also tried. This gives an electromotive force about equal to that of copper-constantan and over six times that of the platinum-platinrhodium element. But the alloy wire proved so inhomogeneous that the accuracy of the element was much less than that of the platinrhodium, and it was accordingly rejected.

Through the courteous coöperation of the Bureau of Standards, a sensitive resistance thermometer in charge of Drs. Dickinson and Mueller of the Bureau was placed alongside the bulb during a part of the measurements, and later a similar instrument ingeniously constructed for the purpose by Dr.

* Zs. anorg. Chem., lxix, 38–46, 1910.

Dickinson was introduced into the re-entrant tube of the gas thermometer bulb itself. The resistance thermometer, which was easily sensitive to a few thousandths of a degree, revealed small temperature fluctuations (0·05°) in the rapidly circulating liquid outside the bulb but no systematic temperature differences. Within the re-entrant tube the fluctuations were no longer felt.

With these precautions to guard against temperature differences about the bulb, temperatures were measured (1) at the boiling-point of benzophenone, (2) at the melting-point of zinc, (3) at the melting-point of antimony.* The three thermoelements, after removal from the nitrate bath, were placed in one or the other of the following: in a vapor bath of boiling benzophenone, in an apparatus for determining the zinc melting-point, or in a similar apparatus containing antimony; after which they were returned to the gas thermometer furnace for the verification of their readings. This series of operations constituted a set of observations as carried out in the tables which follow. Inasmuch as the gas thermometer was brought as close as practicable to the temperature of the points (benzophenone, zinc, etc.) selected as standards, the intermediary role of the thermoelements was merely that of a transfer agent, in which role the individual properties of the thermoelements do not appear at all provided the wires were originally homogeneous. The danger of contamination of the elements and consequent inhomogeneity is negligible at these temperatures. Even if such contamination had crept in, it would have discovered itself in differences between the readings of the elements with each change in the gradient, of which differences no trace was found.

By way of providing a strictly rigorous test of the accuracy of the transfer of temperature from gas thermometer bulb to the reference standards and its independence of the intermediary thermoelement, a special arrangement was devised in the case of zinc as follows: A steel bulb was made up with approximately the dimensions of the gas thermometer bulb and suspended in the same position in the nitrate bath. Enclosed in this bulb was the charge of zinc in its graphite crucible (fig. 2). In this crucible the thermoelement occupied the same position which it occupied in reference to the gas thermometer bulb, and all other conditions were, of course, identical. The zinc melting-points were determined in this way, i. e., in a nitrate bath in which there were no measurable temperature differences in the region about the melting zinc and with the tem-

* The zinc and antimony were the same charges which were used in the previous investigation. The analyses may be found in Pub. 157, pp. 87 and 88; this Journal, xxix, p. 159.

perature gradient along the thermoelements identical with that surrounding the gas thermometer bulb itself.

4. *Boiling Point of Sulphur.*

Finally an attempt was made to establish one temperature in this region from which the intermediary thermoelement should be completely eliminated. The gas thermometer bulb itself was immersed in the vapor of boiling sulphur. For this determination the nitrate bath was replaced by an appropriate sulphur boiling-point apparatus, all other conditions remaining the same. In building this apparatus, which is shown in fig. 3, the experience of the Bureau of Standards was utilized for the most part. To this design certain modifications suggested by the unpublished work of Prof. G. A. Hulett of Princeton were added by way of rendering the determination, as far as practicable, independent of particular experimental conditions employed.

Heat was supplied electrically from a coil of high resistance wire about the sulphur tube, the coil ending about 2^{cm} below the level of the surface of the liquid sulphur (Bureau of Standards usage). An independent coil surrounded the vapor region, separated from it by an annular air space of about 1^{cm} (Hulett). The bulb was surrounded first by a shield of sheet aluminium (Bureau of Standards) with holes near the top and bottom to permit the free circulation of the sulphur vapor and a hole in the center of the bottom diaphram to permit the escape of liquid sulphur which chanced to condense on the shield. The shield afforded protection against any direct interchange of radiation with the furnace or with the boiling liquid and its steep conical roof diverted the condensing liquid sulphur away from the bulb. Subsequently with the purpose of varying these conditions the aluminium shield was replaced by another of similar form but of glass (Hulett) and of somewhat smaller diameter. This was suspended from the conical aluminium roof of the first shield, which now overhung the side walls by several millimeters, with the effect that liquid sulphur condensing upon the cone could drip from the overhang instead of running down the side wall past the bulb. The radiation conditions were also radically altered by this substitution of glass for aluminium both around the bulb and below it.

Further variation was provided by changing the current in the two heating coils. Variations of some 35 per cent in the main coil about the boiling liquid were tried and the upper coil was varied from zero (Bureau of Standards usage) to over 40 per cent of the current in the main coil. Or, in other terms, the 1^{cm} air jacket about the vapor was varied in temperature

from the normal gradient (without heat in the upper coil) to a temperature equal to that of the sulphur vapor itself.

None of these changes produced any measurable change in the temperature of the sulphur vapor as recorded by the gas thermometer provided enough heat was supplied to fill the tube with vapor. During some of the measurements the vapor escaped freely between the glass tube and aluminium cover and burned there.

The remaining details and relative dimensions of the sulphur

FIG. 3.

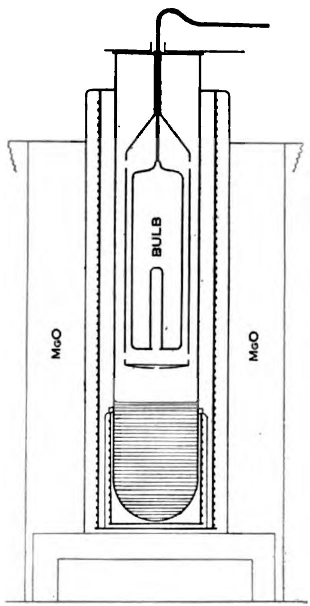

FIG. 3. Apparatus for direct determination of the boiling point of sulphur with the nitrogen thermometer. Scale: 1 to 6·5.

vapor bath will be clear from the diagram (fig. 3), which is drawn to scale. The arrangement shown in the figure is the one with the aluminium shield.

The sulphur used was distilled to free it from a black residue which was found in both of two different preparations of C.P. sulphur. This residue, which is partly if not wholly ferrous sulphide, would probably have had no appreciable effect on the boiling point. After the close of these experiments the sulphur boiling apparatus was sent to the Bureau of Standards, where a number of measurements were made of the tempera-

ture of the vapor within the aluminium shield compared with the corresponding temperature in one of the sulphur baths which Waidner and Burgess* have standardized and described in connection with their measurements with the platinum resistance thermometer. This comparison has been described by Messrs. Dickinson and Mueller.† The differences amounted in maximum to 0·04°, which may afford some measure of the certainty with which the temperature of the sulphur vapor is reproduced in an apparatus differing considerably from the conventional form and dimensions.

At the close of the measurements the gas thermometer bulb and manometer were disconnected. In order to make certain that our calculation of the volume of the unheated space contained no unknown constant error, that portion of this space lying outside the furnace was determined directly, as follows: the mercury was brought up to the fixed point with the capillary open to the air. The connection between the two arms of the manometer was then closed, and a known volume of air (about $0{\cdot}1^{cc}$) was drawn in through the capillary by drawing off a weighed amount of mercury from the short arm. The open end of the capillary was then sealed, the manometer connection reopened, and the mercury again brought up to the fixed point. The pressure necessary to effect this is a measure of the volume of the space in the capillary and connections. The results were:

Direct determinations	$0{\cdot}159^{cc}$
	$0{\cdot}164^{cc}$
Mean	$0{\cdot}162^{cc}$
Calculated in 1909	$0{\cdot}168^{cc}$

The difference is negligible.

Finally, the location on the brass scale of the gas thermometer of the "fixed point" which is situated in the top of the short arm of the instrument and which defines its "constant volume," was redetermined and found to have become displaced by $0{\cdot}18^{mm}$ since the initial determination in 1909. An appropriate correction was accordingly made to this constant in computing the results.

These various checks and verifications complete the observations. The more important constants of the instrument and the formula used in the calculations are reproduced below from the previous paper.‡

* Bull. Bur. Stds., vi, 150–230, 1909.
† J. Washington Acad., ii, 176–180, 1912.
‡ Pub. No. 157, p. 52.

Material of the bulb: pure platinum 80 per cent
pure rhodium 20 per cent
Volume of bulb: $V_0 = 205{\cdot}82^{cc}$
Volume of unheated space: $v_1 = 0{\cdot}309^{cc}$

$$\frac{v_1}{V_0} = 0{\cdot}00150$$

Expansion coefficient of bulb material: $10^6\,\beta = 8{\cdot}79 + 0{\cdot}00161\,t$
Gas: pure nitrogen.
Initial pressure of gas (see Table I): p_0=about 500^{mm}.
Pressure coefficient of gas (see Table II): $\alpha = 0{\cdot}0036679$ to $0{\cdot}0036681$.
Formula used in the computations:

$$t = \frac{1}{p_0 \alpha}\left[p\left(1 + \frac{3\,\beta\,t}{1 + \frac{v_1}{V_0}}\right) - p_0\right]$$

in which p_0 and p are the corrected pressures at 0° and t respectively.

5. *Experimental Results with Nitrate Bath.*

Table I contains the measurements of the zero-point of the instrument before and after each heating and serves to show that its variations are wholly within the accidental errors of reading of barometer and manometer. In the third column p'_0 is the measured initial pressure of the gas in millimeters of mercury at zero degrees. The application of the correction for the "unheated space" gives the pressures (p_0) of column 4.

The measurements included in Table II are introduced merely as a rough check on the pressure coefficient (α) of the gas. A much more accurate determination has been made of this constant for nitrogen by Chappuis* and his value of it ($0{\cdot}0036681$, corresponding to a pressure of 502^{mm}) was used in the calculations which follow. These measurements merely afford a rough confirmation of this value within the somewhat larger limits of error of our instrument. Columns 3 and 4 contain the pressures at the boiling point of water corrected as in Table I.

In Table III, columns 3 and 4 contain the pressure measurements near the three fixed temperatures of reference, reduced as before; t (column 5) is the gas thermometer temperature in the nitrate bath and e (column 6) the corresponding electromotive force of the thermoelement in microvolts; e (column 7) is the electromotive force of the same elements in benzophenone, zinc and antimony respectively and the final column contains the corresponding gas thermometer temperatures.

* Trav. Mem. Bur. Int., vol. xiii, 1907.

TABLE I. Measurements of p_0.

Date	Serial No.	p'_0	p_0
1911	*First Gas Filling.*		
17 Oct.	1	486·03	485·98
19 "	4	486·05	486·00
21 "	7	486·06	486·01
21 "	8	486·05	486·00
	Second Gas Filling.		
26 "	9	501·91	501·86
27 "	10	501·91	501·86
31 "	12	501·87	501·82
31 "	13	501·88	501·83
2 Nov.	15	501·94*	501·89*
6 "	17	501·89	501·84
6 "	18	501·91	501·86
11 "	22	501·84	501·79
15 "	24	501·81	501·76
18 "	26	501·87	501·82
20 "	29	501·81	501·76
6 Dec.	30	501·79	501·74
8 "	35	501·84	501·79
11 "	38	501·82	501·77
22 "	43	501·83	501·78
27 "	48	501·77	501·72
1912			
2 Feb.	54	501·86	501·81
15 "	61	501·88	501·83

TABLE II. Measurements of p_{100}.

Date	Serial No.	p'	p	Barom.	t	a
1912						
15 Feb.	58	683·51	683·69	754·3	99·790	0·0036684
"	59	683·49	683·67	753·7	99·768	0·0036685
"	60	683·46	683·64	753·4	99·757	0·0036686
					Mean	0·0036685

* High wind, both mercury columns varying.

TABLE III. Gas Thermometer Measurements in Nitrate Bath.

Date	Serial No.	p'	p	t	e	e at fixed point	Temp. of fixed point
			Benzophenone, boiling point.				
1911							
18 Oct.	2	1023·36	1024·47	306·97	2379.8	2369·2	305·82
20 "	6	1020·60	1021·69	305·37	2364·7	2369·2	305·86
30 "	11	1053·07	1054·18	304·91	14944*	14996	305·82
1 Nov.	14	1054·84	1055·97	305·91	15002*	15005	305·96
						Mean	305·87
			Zinc, melting point.				
18 Oct.	3	1216·27	1218·05	418·78	3429·4	3433·7	419·24
20 "	5	1215·85	1217·61	418·53	3427·1	3433·7	419·24
4 Nov.	16	1256·96	1258·76	419·32	3432·2	3433·7	419·48†
17 "	25	1256·54	1258·35	419·18	3432·9	3433·7	419·27
18 "	27	1255·85	1257·69	418·80	3429·0	3433·7	419·31
18 "	28	1254·96	1256·80	418·29	3423·8	3433·7	419·36
						Mean	419·28
			Antimony, melting point.				
10 Nov.	19	1627·10	1630·58	629·66	5525·8	5527·7	629·84
10 "	20	1627·09	1630·57	629·66	5525·2	5527·7	629·90
10 "	21	1626·96	1630·44	629·58	5524·2	5527·7	629·92
14 "	23	1625·08	1628·59	628·54	5515·5	5527·7	629·73
						Mean	629·85

* Copper-constantan thermoelement.
† Wide temperature variation on manometer. This value is omitted from the mean.

6. *Interpolation Formula.*

For convenient interpolation with thermoelements in this temperature region, the following equation is accurate within 0·3° as far as the melting point of copper, but may not be used beyond that temperature or below the boiling point of benzophenone:

$$e = -308 + 8{\cdot}2294\,t + {\cdot}001649\,t^2$$

In terms of the standard element used in our recent publication upon this subject,* this equation gives the following electromotive forces:

* Publication No. 157, Carnegie Institution of Washington, pp. 109 *et seq.* For the measurement and interpolation of temperatures above 1082·6°, the reader is referred to the same pages; for temperatures below 305·9° to page 536, following (Adams and Johnston).

Fixed point	Temperature (Nitrogen Thermometer)	Standard thermo-element (in microvolts)	E. M. F. calculated (in microvolts)	Difference Obs. − Cal.	
				Mv.	Degr.
Benzophenone (boiling point)	305·9°	2365	2364	+1	+0.1
Cadmium (melting point)	320·8	2502	2502	0	0·0
Zinc (melting point)	419·3	3429	3432	−3	−0·3
Antimony (melting point)	629·8	5530	5529	+	+0·1
Silver (melting point)	960·0	9113	9112	+1	+0·1
Gold (melting point)	1062·4	10295	10296	−1	−0·1
Copper (melting point)	1082·6	10534	10534	0	0·0

7. *Experimental Results on Sulphur.*

Table IV contains the measurements made in the sulphur vapor bath. p' and p represent the gas thermometer pressures corrected as before, t the resulting temperature, followed by the barometer reading reduced to sea level at lat. 45°, and the boiling temperature reduced to 760^{mm} pressure.

TABLE IV. Direct Measurement of Boiling Point of Sulphur.

Date.	Serial No.	p'	p	t	Barom.	t at 760^{mm}
1912.						
31 Jan.	49	1298·77	1301·07	443·21	746·3	444·45
"	50	1298·83	1301·16	443·26	747·0	444·43
"	51	1298·84	1301·17	443·27	747·0	444·44
1 Feb.	52	1299·14	1301·44	443·42	748·4	444·47
"	53	1299·14	1301·44	443·42	748·2	444·48
3 Feb.	55	1299·70	1302·00	443·73	752·0	444·45
"	56	1299·50	1301·81	443·62	751·4	444·40
"	57	1299·55	1301·87	443·66	751·0	444·47
					Mean	444·45

TABLE V. Gas Thermometer Determinations of the Boiling Point of Sulphur since 1890.

Date	Author	Thermometer	Gas	Pressure mm.	Original figure	Corrected figure	Const. vol. nitrogen scale			Thermodynamic scale	Notes
							$p_\circ = 1000$	$p_\circ = 760$	$p_\circ = 500$		
1890	Callendar and Griffiths	Const. pr.	Air	760	444·53*	....	444·71	444·76	444·81	444·91	Indirect through Pt. res. therm.
1902	Chappuis and Harker	Const. vol.	Nitrogen	530	445·2†	444·7‡	444·60	444·65	444·70	444·80	Indirect through Pt. res. therm.
1908	Eumorfopoulos	Const. pr.	Air	760	443·58§	444·55‖	444·73	444·78	444·83	444·93	Direct.
1911	Holborn and Henning	Const. vol.	Hydrogen Helium Nitrogen	623 612 625	444·51 ¶ (444·39)	....	443·31	444·36	444·41	444·51	Indirect through Pt. res. therm.
1912	Day and Sosman	Const. vol.	Nitrogen	502	444·45	....	441·35	444·40	444·45	444·55	Direct

* Phil. Trans., clxxxii, A, 119–157, 1891.
† Trav. Mem. Bur. Int., xii, 1902.
‡ Ibid., p. 90.
§ Proc. Roy. Soc., lxxxi, A, 339–362, 1908.
‖ Proc. Roy. Soc., lxxxiii, A, 106–108, 1910.
¶ Ann. Physik, xxxv, 761–774, 1911. The value given for "Nitrogen" is calculated from the authors' table of experimental results. They give in their paper only the final mean value on the thermodynamic scale.

In Table V are brought together all the gas thermometer determinations of the boiling point of sulphur since 1890 with the necessary information for an intelligent comparison of the determinations. Column 5 contains the initial pressure of the gas used, and column 6 the original value published by the author with a reference to the place of publication. Two of these determinations were subsequently corrected by the authors themselves. These corrections (with the reference) are given in column 7.

Inasmuch as these various determinations were made under somewhat different gas conditions, the results are not directly comparable without reduction to some common unit. The four columns which follow contain such reductions for purposes of convenient comparison. Our own observations are directly comparable with the numbers contained in the column "Const. vol. nitrogen scale, $p_0 = 500$." The fairest comparison is afforded by reduction to the thermodynamic scale, in view of the fact that the different gases used by the various observers depart in varying degree from the behavior of a perfect gas expanding at constant volume from the same initial pressure. It should be noted that the small differences between the four columns are really arithmetical and not experimental, since none of the original determinations can claim an accuracy closer than 0·05°.

The Callendar and Griffiths determination above, which is often quoted as direct, is in reality indirect. In his first investigation (Phil. Trans. 1887) Callendar showed that his parabolic formula represented within 1° the variation of the resistance of platinum with the temperature as determined by the constant pressure air thermometer as far as 600°. In this later work (Phil. Trans. 1891) he showed by a comparison of two resistance thermometers with the air thermometer, using sulphur merely as a constant temperature bath, that his original value of $\delta = 1{\cdot}57$ would still represent the results for these thermometers within the limits of error. This value of δ was then used to calculate the sulphur boiling point determined with several platinum thermometers in the usual (Meyer) form of sulphur boiling tube.*

* The air thermometer observations of Callendar and Griffiths in sulphur vapor comprise fourteen readings, made between 4:52 and 5:30 p. m. on Friday, September 12, 1890, and between 8:25 and 9:07 the following morning, as follows (Phil. Trans., 182 A, 1891, p. 139):

Friday, Sept. 12, 1890. Time	Temperature	*Saturday, Sept. 13, 1890.* Time	Temperature
4:52	444·52°	8:25	444·51°
5:02	444·90	8:28	444·51
5:06	444·68	8:38	444·52
5:18	444·77	8:42	444·53
5:21	444·79	8:48	444·54
5:26	444·94	8:50	444·52
5:30	444·98	9:07	444:61

8. *Summary.*

The new gas thermometer temperatures which this investigation has given us are brought together in Table VI, expressed (column 2) in terms of nitrogen expanding at con-

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Concerning the sulphur used with the air thermometer, the following information is offered (p. 140):

"The sulphur used on the Friday was poured out of the apparatus before it solidified. It was found to be much discoloured, owing to the presence of various impurities due to residues of oil, red lead, etc., used in fitting the iron tubes together. Fresh sulphur was used on the Saturday, and this, on examination, appeared to have suffered hardly any change."

Notwithstanding the fact that the conditions surrounding the observations of Saturday appear the more favorable, these are rejected, with this statement (p. 140):

"The mean values of t deduced from the observations with the platinum thermometers M_1 and M_2, by assuming the value $\delta=1\cdot570$ in formula (d), are:

On Friday, $t = 444\cdot78°$ C.
On Saturday, $t = 444\cdot84°$ C.

"The mean values of t deduced from the simultaneous observations with the air thermometer are:

On Friday, $t = 444\cdot80°$ C.
On Saturday, $t = 444\cdot52°$ C.

"The value found on Friday is seen to agree perfectly with that deduced from the observations with the platinum thermometers. The value of t deduced from Saturday's observations is $0\cdot32°$ too low; but it is probable that the value of mk, used in reducing the observations taken on that day, is a little too great."

" . . . . We may, therefore, conclude that these experiments, so far as they go, are a complete verification of the value of δ found in 1887, and show that the platinum wire has not altered appreciably in the interval."

Of the apparatus used, the following details are taken from another part of the paper (p. 120):

"Two new thermometers, M_1 and M_2, were therefore constructed out of the remainder of the old spiral [1887], and were very carefully compared with the air thermometer at a temperature very near the boiling-point of sulphur. . . . The result agrees perfectly with that found in 1887, and shows that the value of the δ-coefficient has not altered appreciably in the interval.

"The apparatus used for this comparison [the sulphur bath used with the air thermometer], although useful as a constant high-temperature bath, was not very well suited for determining the actual temperature of the sulphur vapour. Another series of experiments was therefore undertaken in a Meyer tube, which proved to be more convenient for the purpose."

On page 145 occurs the following statement of the final result (obtained in the Meyer tube with resistance thermometers only):

"Assuming $\delta = 1\cdot570$ for thermometers L, M_1 and M_2, we find for the corresponding air-temperature the value

$$\underline{t = 444\cdot53° \text{ C.}}$$

We believe this to be within $0\cdot1°$ of the true temperature of the vapour of sulphur boiling freely under a pressure of 760^{mm}."

The value assumed for δ is entirely dependent upon the temperature determined with the air thermometer, and can not be more accurate than this determination. From the air thermometer measurements above quoted, $0\cdot5°$ would appear to be a fairer measure of the uncertainty of the final sulphur point.

stant volume from an initial pressure of 760^{mm} and (column 3) in terms of the thermodynamic scale. These values replace the corresponding temperatures published in our papers to which reference has been made.

TABLE VI.—SUMMARIZED TABLE.

Point	Temperature		Notes
	Const. vol. $p_o=1$ at.	Thermo-dynamic	
Benzophenone (Kahlbaum) boiling pt. at 760^{mm}	305·85	305·9	Transferred by platin-rhodium and copper-constantan thermoelements.
Cadmium, melting pt.	320·8	320·9	Interpolated.
Zinc, melting pt.	419·3	419·4	Transferred by thermo-elements.
Sulphur, boiling pt. at 760^{mm}	444·40	444·55	Direct.
Antimony (Kahlbaum), melting pt.	629·8	630·0	Transferred by thermo-elements.
Aluminum, melting point	658·5	658·7	Interpolated.

Finally a comparative table is added showing in terms of the same (thermodynamic) scale a comparison of our results with those obtained by Holborn and Henning in the latest work published from the Reichsanstalt.

TABLE VII.—COMPARATIVE TABLE.
Thermodynamic Scale.

Point	Holborn and Henning 1911	Day and Sosman 1912
Benzophenone	305·9	305·9
Cadmium	320·9	320·9
Zinc	419·4	419·5
Sulphur	444·51	444·55
	Holborn and Day	
Antimony	630·6	630·0

Geophysical Laboratory,
Carnegie Institution of Washington,
March, 1912.

ART. XLIV.—*A Note on the Standard Scale of Temperatures between 200° and 1100°;* by L. H. ADAMS and J. JOHNSTON.

A YEAR ago, at the time when the original measurements recorded in this note were completed, there was an outstanding uncertainty of about 1° in the temperature scale around 400°; at the present time, by reason of the concordant results obtained in the best series of gas thermometer determinations within this region—those recently published by Holborn and Henning* and Day and Sosman†—this uncertainty is not more than 0·1°, and is probably less than this, at temperatures up to 500°. The definite establishment of the temperature scale renders the conclusions presented in this note to some extent supererogatory; nevertheless, it has been thought worth while to present them, as, at the least, they serve to confirm those expressed in the preceding paper.

In what follows, we present independent thermoelectric measurements at the boiling points of naphthalene and benzophenone and of the freezing points of four metals—tin, bismuth, cadmium and lead; the agreement of these results with the best resistance thermometer measurements of the same fixed points shows that the thermocouple is not inferior to the resistance thermometer as an accurate temperature-measuring device within the temperature range in question. Moreover, we propose to show that the most thorough and most extensive series of resistance thermometer measurements—those of Waidner and Burgess, made at the Bureau of Standards—are also in remarkable agreement over the whole range of temperature (up to 1100°) with the gas thermometer measurements of Day and Sosman, when they are expressed in the same scale. At the same time this comparison shows that, if we consider all of the points,‡ excepting sulphur, to be fixed by the gas thermometer work, and on this basis set up an interpolation formula and calculate therefrom the boiling point of sulphur, the resistance thermometer measurements lead to a value (444·55°) identical with the gas thermometer determinations.

Calibration of the Thermoelements.

In connection with another investigation§ it became necessary to calibrate carefully some copper-constantan thermo-

* Ann. Physik, xxxv, 861–74, 1911. † Preceding paper.

‡ Namely, the boiling points of naphthalene and benzophenone, and the freezing points of tin, cadmium, zinc, antimony, silver and copper.

§ This Journal (4), xxxi, 501–17, 1911.

couples, which were then employed in determining the freezing points of the metals tin, bismuth, cadmium and lead.* This calibration has been described in the paper just referred to; but the account there given must be amplified by the following additions and corrections, which are rendered necessary by the slight changes in the temperature scale resulting from the new and more accurate gas thermometer determinations at temperatures up to 500°.

It has been found† that too much reliance can not be placed on the readings of copper-constantan thermoelements at the zinc point (419·4°), for some diminution of electromotive force sets in, not serious, but sufficient to preclude the most accurate measurement. For this reason we have ceased to make use of the zinc point as a calibration temperature; for the same reason, we give the calibration curve only up to about 360°.

The calibration temperatures, expressed in the corrected scale, together with the corresponding values of the electromotive force of the standard element, are given in Table I.

TABLE I.—Calibration Temperatures.

t	e in microvolts		Difference	
	Observed	Calculated[2]	In microvolts	In degrees
0	0	0	0·0	0·0
25·00	979	980·0	−1·0	−·025
50·00	2012	2012·7	+0·7	+·016
75·00	3096	3095·8	+0·2	+·005
100·00	4227	4226·1	+0·9	+·019
217·95	10119	10119·3	−0·3	−·005
306·1[1]	15007	15007·0	0·0	0·0

[1] The benzophenone used was from Merck, which melts (at 46·9°) 0·8° lower, and boils 0·2° higher, than that obtained from Kahlbaum (Waidner and Burgess, Bull. Bur. Standards, vii, 6). The f. p. of our Merck benzophenone was also 46·9°; consequently we have added 0·2° to the accepted b. p. (305·9°) of Kahlbaum benzophenone.

[2] From the equation $e=38{\cdot}105\,t+0{\cdot}04442\,t^2-0{\cdot}00002856\,t^3$, obtained by the method of least squares, e as measured at the zinc point (419·4°) was 21755 microvolts; the equation gives 21688, which does not differ by more than what one might expect in view of the extrapolation through more than 110°.

To reproduce the above data, a quadratic equation is insufficient, except over a very short range, and so is the cubic

* Loc. cit., p. 508.

† Cf. Day and Sosman, preceding paper, p. 521.

Table II.—Standard Calibration Curve for copper-constantan difference for every 100 microvolts. Fixed points: 0°, **0**; 100°, Kahlbaum), **14996.**

e	0		1000		2000		3000		4000	
0	0·		25·50		49·70		72·83		95·08	
		2·62		*2·47*		*2·36*		*2·26*		*2·18*
100	2·62		27·97		52·06		75·09		97·26	
		2·60		*2·46*		*2·35*		*2·25*		*2·17*
200	5·22		30·43		54·41		77·34		99·43	
		2·59		*2·45*		*2·33*		*2·25*		*2·17*
300	7·81		32·88		56·74		79·59		101·60	
		2·57		*2·44*		*2·33*		*2·24*		*2·16*
400	10·38		35·32		59·07		81·83		103·76	
		2·55		*2·43*		*2·32*		*2·23*		*2·15*
500	12·93		37·75		61·39		84·06		105·91	
		2·54		*2·41*		*2·31*		*2·22*		*2·14*
600	15·47		40·16		63·70		86·28		108·05	
		2·53		*2·40*		*2·30*		*2·21*		*2·14*
700	18·00		42·56		66·00		88.49		110·19	
		2·51		*2·39*		*2·28*		*2·20*		*2·13*
800	20·51		44·95		68·28		90·69		112·32	
		2·50		*2·38*		*2·28*		*2·20*		*2·12*
900	23·01		47·33		70·56		92·89		114·44	
		2·49		*2·37*		*2·27*		*2·19*		*2·12*
1000	25·50		49·70		72·83		95·08		116·56	

e	10000		11000		12000		13000		14000	
0	215·72		234·32		252·61		270·63		288·41	
		1·87		*1·84*		*1·81*		*1·79*		*1·77*
100	217·59		236·16		254·42		272·42		290·18	
		1·87		*1·84*		*1·81*		*1·79*		*1·76*
200	219·46		238·00		256·23		274·21		291·94	
		1·87		*1·84*		*1·81*		*1·78*		*1·76*
300	221·33		239·84		258·04		275·99		293·70	
		1·87		*1·83*		*1·81*		*1·78*		*1·76*
400	223·20		241·67		259·85		277·77		295·46	
		1·86		*1·83*		*1·80*		*1·78*		*1·76*
500	225·06		243·50		261·65		279·55		297·22	
		1·86		*1·83*		*1·80*		*1·78*		*1·75*
600	226·92		245·33		263·45		281·33		298·97	
		1·85		*1·82*		*1·80*		*1·77*		*1·75*
700	228·77		247·15		265·25		283·10		300·72	
		1·85		*1·82*		*1·80*		*1·77*		*1·75*
800	230·62		248·97		267·05		284·87		302·47	
		1·85		*1·82*		*1·79*		*1·77*		*1·75*
900	232·47		250·79		268·84		286·64		304·22	
		1·85		*1·82*		*1·79*		*1·77*		*1·75*
1000	234·32		252·61		270·63		288·41		305·97	

thermo-elements, giving the temperature and the temperature
4226 ; 217·95° (naphthalene), **10119**; 305·9° (benzophenone,

5000		6000		7000		8000		9000		e
116·56		137·40		157·66		177·43		196·77		0
	2·11		*2·05*		*2·00*		*1·95*		*1·91*	
118·67		139·45		159·66		179·38		198·68		100
	2·10		*2·04*		*2·00*		*1·95*		*1·91*	
120·77		141·49		161·66		181·33		200·59		200
	2·10		*2·04*		*1·99*		*1·94*		*1·90*	
122·87		143·53		163·65		183·27		202·49		300
	2·09		*2·03*		*1·98*		*1·94*		*1·90*	
124·96		145·56		165·63		185·21		204·39		400
	2·09		*2·03*		*1·98*		*1·94*		*1·90*	
127·05		147·59		167·61		187·15		206·29		500
	2·08		*2·02*		*1·97*		*1·93*		*1·89*	
129·13		149·61		169·58		189·08		208·18		600
	2·08		*2·02*		*1·97*		*1·93*		*1·89*	
131·21		151·63		171·55		191·01		210·07		700
	2·07		*2·01*		*1·96*		*1·92*		*1·89*	
133·28		153·64		173·51		192·93		211·96		800
	2·06		*2·01*		*1·96*		*1·92*		*1·88*	
135·34		155·65		175·47		194·85		213·84		900
	2·06		*2·01*		*1·96*		*1·92*		*1·88*	
137·40		157·66		177·43		196·77		215·72		1000

15000		16000		17000		18000		......		e
305·97		323·35		340·58		357·66		......		0
	1·75		*1·73*		*1·71*		....		....	
307·72		325·08		342·29		......		......		100
	1·74		*1·73*		*1·71*		....		....	
309·46		326·81		344·00		......		......		200
	1·74		*1·73*		*1·71*		....		....	
311·20		328·54		345·71		......		......		300
	1·74		*1·72*		*1·71*		....		....	
312·94		330·26		347·42		......		......		400
	1·74		*1·72*		*1·71*		....		....	
314·68		331·98		349·13		......		......		500
	1·74		*1·72*		*1·71*		....		....	
316·42		333·70		350·84		......		......		600
	1·74		*1·72*		*1·71*		....		....	
318·16		335·42		352·55		......		......		700
	1·73		*1·72*		*1·71*		....		....	
319·89		337·14		354·26		......		......		800
	1·73		*1·72*		*1·70*		....		....	
321·62		338·86		355·96		......		......		900
	1·73		*1·72*		*1·70*		...		....	
323·35		340·58		357·66		......		......		1000

equation of the form $t=Ae+Be^2+Ce^3$;* but they can, as we found, be fitted very closely by the inverse form of function, $e=At+Bt^2+Ct^3$. Accordingly, on this basis a least square solution for all the points in Table I was made; this resulted in the equation

$$e=38{\cdot}105\,t+0{\cdot}04442\,t^2-0{\cdot}00002856\,t^3,$$

from which the figures in the third column of Table I have been computed. The agreement is excellent; it cannot, however, be used as a valid argument in favor of the accuracy of either the temperature scale or of the measurements, as anyone can readily convince himself by working with a number of similar cubics. Incidentally, it may be noted that in making such a least square solution, it is inadmissible to lighten the work by dividing through by t, which would necessitate only the least square solution of a quadratic; for the solution obtained by proceeding in this way, although apparently a cubic equation, is that appropriate to the condition that the deviation of the curve from the values of e/t (instead of e) shall be a minimum.

By means of this equation, values of e and of de/dt for each 10° up to 360° were computed; the slight irregularities being evened out by adjustment of the successive differences. By interpolation from these results, and adjustment of the successive differences again, a table was constructed giving t for each 100 microvolts; this is presented in Table II,† to which are also appended the E. M. F.'s corresponding to the fixed reference points.

This table may be used for any copper-constantan element with the aid of its deviation curve, which is obtained by plotting at several‡ known temperatures the differences between the readings of the element in question and the standard curve.§ Its use thus saves much recalculation of thermoelement curves. The absolute uncertainty of temperatures deduced from the above table should, we believe, not now exceed 0·1°; temperature differences over a small range are probably accurate at least to 0·02°. For this reason the values of temperatures and differences in Table II are given to hundredths of degrees.

The Identity of the Readings of Thermoelement and Resistance Thermometer at Boiling Points and Melting Points.

The initial series of measurements gave differences between the freezing point of tin and the naphthalene point on the one

* This was tried because its use would have saved so much trouble in calculating the most convenient form of table—that giving t for round values of e.

† This table replaces Table I of the previous publication (loc. cit., p. 510).

‡ For accurate work, comparison at a number of temperatures is advisable, since the slope of the deviation curve is likely to change sign once or oftener.

§ This matter is more fully treated by Sosman, this Journal, xxx, 7, 1910.

hand and between the freezing point of cadmium and the benzophenone point on the other,—using our own apparatus and materials—which were 0·2° higher than the corresponding differences obtained by Waidner and Burgess at the Bureau of Standards. This lack of agreement disappeared* when we determined all the points on the identical samples of material used by Waidner and Burgess. This we were enabled to do through the kindness of Dr. G. K. Burgess in lending us his boiling point apparatus and his pots of tin, cadmium and lead, and we desire here to acknowledge our indebtedness to him.

TABLE III.

Boiling Point of Naphthalene and Benzophenone.

Substance	Source	Apparatus	Thermocouple[1]	From Thermoelectric measurements (Adams & Johnston): Microvolts	From Thermoelectric measurements (Adams & Johnston): Degrees	From Resistance Thermometer measurements (Waidner & Burgess): As given by them[2]	From Resistance Thermometer measurements (Waidner & Burgess): When reduced to our scale[3]
Naphthalene	Merck	A	E	1585·7[4]	(217·95)	218·0	217·97
	Kahlbaum	B	E	1585·3			
	Kahlbaum	B	C_1	10119·			
	Merck	A	C_1	10119·[4]			
	"	"	C_3	10118·5			
	"	"	C_2	10120·			
Benzophenone	Merck (b)	A	E	2366·2	(306·1)	306·2	306·11
	" (a)	"	"	2366·3			
	" "	S	C_1	15008·			
	" "	A	C_1	15007·[4]			
	" "	S	C_2	15010·			
	" "	A	C_3	15004·			
	" (b)	"	C_3	15005·5[4]			

[1] Couple E is of Pt—PtRh; C_1, C_2, C_3, are of copper-constantan.

[2] Bull. Bur. Standards, vii, 4, 5 (reprint No. 148).

[3] The values given in the last column have been reduced from those in the column to the left by means of the differences between the scales as determined in a way to be described later (p. 543); i. e., these values are on the basis that the b. p. of sulphur is 444 55°.

[4] Mean of two or more determinations often separated by a monthor so in time. The maximum deviation from the mean in any of these cases was 0·03°.

* The divergence was due to slight impurities in our tin and to the fact that the benzophenone used was from Merck (cf. footnote to Table 1).

Freezing Points of Metals.

Metal	Source	Quantity of metal grms.	Thermo-couple[1]	From Thermoelectric measurements (Adams & Johnston) Microvolts	Degrees	From Resistance Thermometer measurements (Waidner & Burgess) As given by them[2]	When reduced to our scale[3]
Sn	Kahlbaum	1500	C_1	10861·	231·75	231·92	231·88
		"	C_1	10859·	231·71		
		"	C_3	10863·	231·79		
		200	C_3	10856·	231·67		
		200	E	1706·	231·9		
		"	"	1706·[4]	231·9		
		1500	"	1706·	231·9		
		"	"	1706·	231·9		
Bi	J.T.Baker		C_1	13020·	270·99	. . .	. . .
			C_1	13015·	270·90		
Cd	Kahlbaum		C_1	15860·	320·92	321·01	320·92
			C_3	15858·	320·92		
			E	2502·5	320·9		
Pb	Kahlbaum		E	2560·5	327·2	327·27	327·19
			C_1	16227·	327·28		
			C_3	16226·	327·30		

[1] Couple E is of Pt—PtRh; C_1, C_2, C_3, are of copper-constantan.
[2] Bull. Bur. Standards, vi, 173 (reprint No. 124).
[3] The values given in the last column have been reduced from those in the column to the left by means of the differences between the scales as determined in a way to be described later (p. 543); i. e., these values are on the basis that the b. p. of sulphur is 444·55°.
[4] Melting point.

In Table III we present our results. In the boiling point experiments, three forms of apparatus were used; one (B in the table) of glass,* with an aluminium shield for the thermocouple; the second (A) of brass, with an inner tube of thin copper to prevent radiation; and the third (S) similar to the second, but of slightly different dimensions. Four different elements were used; one (E) of platinum-platin-rhodium, the other three (C_1, C_2, C_3) of copper-constantan (No. 30 wire = $0{\cdot}25^{mm}$ diam.).

* Lent to us by Dr. Burgess.

The electromotive forces at the freezing points were reduced to degrees with the aid of Table II; the boiling points were reduced to normal pressure by means of this table and the formulæ: for naphthalene, $t_{760} = t - 0{\cdot}058\ (p-760)$; for benzophenone, $t_{760} = t - 0{\cdot}063\ (p-760)$. The freezing points have been given to hundredths of a degree, as relative values for purposes of comparison only; their absolute accuracy is of the order of 0·1°.

This table shows that the boiling points are independent of the apparatus and sample of material employed, and that the freezing points can be reproduced satisfactorily on different days and with varying set-up; e. g., the results are independent of the size and kind of tube—glass or porcelain—used to protect the thermocouple from the metal, and of the size of the charge.

In order to make the data of Waidner and Burgess more truly comparable with our own, we have reduced them to the scale of temperature on which our own values are based (cf. *postea*, Table V), and present these reduced values in the last column of Table III. The differences between the values for the adjacent freezing and boiling points are compared in Table IV with the analogous differences derived from our thermoelectric measurements.

Table IV.—Comparison of Temperature Intervals as measured by Thermo-elements and by the Resistance Thermometer.

Interval	Temperature difference as derived from measurements with				
	Thermoelements			Resistance Thermometer	
	E*	C_1	C_2	Waidner & Burgess	Holborn & Henning
Sn-naphthalene	13·9	13·78	13·78	13·91	13·87
Cd-benzophenone, Merck	14·8	14·82	14·82	14·81	. . .
Cd-benzophenone, Kahlbaum	15·0	15·02	15·02	15·01	15·03
Pb—Cd	6·3	6·36	6·38	6·43	. . .

The differences, therefore, as determined by us with platin-rhodium and copper-constantan thermoelements in various forms of apparatus on the one hand, and with resistance thermometers at the Bureau of Standards or at the Reichsanstalt on the other, agree very satisfactorily. This proves conclu-

* When reading only to one microvolt, as we were, it is illusory to give the readings of the platin-rhodium element closer than the nearest tenth of a degree.

sively, that there is no systematic deviation whatever, within the range of these measurements, between the readings of these two kinds of thermometers—either at boiling points or at melting or freezing points—when both are calibrated with reference to the same temperature scale.

This position is confirmed by a direct comparison of the series of measurements by Waidner and Burgess of the resistances of platinum thermometers with the recent gas thermometer measurements of Day and Sosman,* transferred by means of thermoelements to the same fixed points. So far we have dealt with temperatures less than about 330°; but the comparison just referred to enables us to extend the same conclusion to the copper point (1083°), beyond which the readings of the resistance thermometer are no longer trustworthy.

Comparison of the Series of Resistance Thermometer Measurements (Waidner and Burgess) with Gas Thermometer Determinations (Day and Sosman) at the same Fixed Points.

For a fair comparison it is essential that the results be expressed in the same scale of temperatures; for this we have adopted the thermodynamic scale. We have accordingly applied the appropriate corrections, taking a mean of the correction numbers collated by Buckingham,† to the results of Day and Sosman, which were determined on the constant volume scale. The uncertainty of the gas thermometer determinations is indeed comparable with the magnitude of these corrections; nevertheless, we have, for the sake of definiteness, considered it advisable to apply them.

The results as given by Waidner and Burgess‡ were derived by means of the Callendar formula,§ the third calibration temperature being the sulphur boiling point taken as 444·70°. In order to refer these values to the comparison scale, it seemed simplest to substitute in the Callendar equation the simulta-

* This Journal, xxix. 93–161, 1910; Carnegie Institution of Washington, Publication No. 157, 1911. Cf. also preceding paper.

† Bull. Bur. Standards, iii, 288–9, 1907; (reprint No. 57).

‡ *Ibid.*, vi, 150–223, 1910, (reprint No. 124); vii, 1–11, 1910, (reprint No. 143).

§ The Callendar formula is $t-pt = \delta\left(\frac{t}{100} - 1\right)\frac{t}{100}$, where t is the true temperature, and pt (the so-called platinum temperature) is defined by the relation

$$pt = \frac{100\,(R_t - R_0)}{R_{100} - R_0}$$

(R is the resistance at $t°$). δ is a deviation constant derived by means of the formula from the third calibration temperature (usually the sulphur boiling point); for pure platinum δ, as thus obtained, is close to 1·50. The formula is essentially a simple quadratic relation of the form

$$R_t = R_0 + at + bt^2$$

neous values of the thermodynamic temperature (t) and the platinum temperatures of a single resistance thermometer* as measured by Waidner and Burgess, and to compute in this way the corresponding values of δ'. These values vary irregularly at the lower temperatures, as might be expected, since the influence of variation of δ is small when t is small; but at the higher temperatures they show a distinct upward trend, and can be represented very fairly by the relation $\delta' = 1{\cdot}489 + 0{\cdot}000015\,t$. These values of δ' were combined with the respective platinum temperatures to give new values of the temperature, which were then subtracted from the temperatures as given by Waidner and Burgess;† thus giving the differences between the two scales at these points. These differences were applied to the average values given by Waidner and Burgess, giving the "corrected" average temperatures presented in Table V, column II. Alongside of this we have tabulated (column I) the temperatures on the thermodynamic scale as derived from the work of Day and Sosman, and (in column III) the differences between these two sets of measurements.

The differences at the tin and zinc points are no doubt due to the fact that in these two cases the determinations were made on different samples of metal; with these two slight exceptions the agreement is all that could be desired. This concordance shows further that if we derive an interpolation formula for the resistance thermometer based on all of the points excepting sulphur, and calculate by means of this formula the boiling temperature of sulphur, we obtain a result identical with the direct gas thermometer determination of this fixed point.

If we recalculate the above temperatures, using a fixed value of δ based on the newer determinations of the sulphur point, we obtain results which are practically identical with those of column II (Table V) except at the silver and copper points, which would on this basis be lower by 0·6° and 0·9° respectively. This silver point would still be within the limits of accuracy of the gas thermometer measurements at that point, but the divergence at the copper point (1·3°) is somewhat greater than the probable error.

This raises the question of the range through which the simple, and very convenient, Callendar formula is applicable in accurate work. It does not hold for impure platinum or for palladium;‡ nor does it hold for pure platinum at all tem-

* No. 1787C; this instrument was used over the widest range and appears to be the most satisfactory of those used at the Bureau of Standards.

† That is, the temperatures as derived from a fixed δ, obtained by calibration at 0°, 100°, and the S b.p. taken as 444·70°.

‡ Waidner and Burgess, Bull. Bureau Standards, vi, 176, 183.

Table V.—Comparison of the "Corrected" Temperatures (measured by the Resistance Thermometer) with Determinations by the Gas Thermometer and with Thermoelements. Thermodynamic Scale.

		Temp. based on gas thermometer measurements (D. & S.) I[1]	"Corrected" temps. from resistance thermometer measurements (W. & B.) II	Differences II — I
Nph.	b.p.	217·95[2]	217·97	+0·02
Sn	f.p.	231·73[3]	231·88	·15
Bnz	b.p.	305·90[4]	305·91	·01
Cd	f.p.	320·92[3]	320·92	·00
Pb	f.p.	327·39[3]	327·35	— ·04
Zn	f.p.	419·4[4]	419·24	— ·16
S	b.p.	444·55[5]	444·55	·00
Sb	f.p.	630·0[4]	630·36	+ ·36
Ag	f.p.	960·4[4]	960·7	+ ·3
Cu	f.p.	1083·2[4]	1082·8	— ·4

[1] The temperatures are given to hundredths for purposes of comparison.
[2] Holborn and Henning, Ann. Physik, xxxv, 761–74, 1911.
[3] From the thermoelectric measurements of Table IV above.
[4] Temperatures transferred from gas thermometer measurement to fixed point by thermocouples.
[5] Direct gas thermometer determination.

peratures below 0° C. Indeed Travers and Gwyer say: "A standard scale of temperature, based on Callendar's three fixed points, using standard wire, and taking 1·5 for the value of δ, would obviously lead to absurd results at low temperatures; and the converse may be said of our own observations,"* and conclude that the Callendar formula cannot be made use of except for interpolation. There is thus ground for believing that the accuracy of the results calculated from the change of resistance of *pure* platinum by means of the simple Callendar formula is, to some extent, fortuitous. The small variation of δ introduces uncertainties which would appear to be too great for the most accurate work, except over the temperature range included between the fixed calibration points (0°—444·55°), and a short region beyond (perhaps to 750°).† On the other hand, it must be admitted, that the cubic term (which expresses the variation of δ with the temperature) is very small—so small that its effect is scarcely greater than the uncertainty in the gas thermometer determinations at higher temperatures.

* Proc. Roy. Soc. London, lxxiv, 1904–5.
† The effect of slight changes of δ on the calculated temperatures may be gauged from the following: that a change of 0·2° in the boiling point of sulphur changes δ by 1 per cent (and proportionally for other small changes); this in turn affects temperatures of 300°, or lower, by 0·1° or less, but affects the antimony point by 0·5°, and the copper point by 1·6°.

In this connection one point remains to be noted, namely, the accuracy of the Reichsanstalt scale in the region 1000–1100°. Holborn and Valentiner state in one place* that the uncertainty at 1000° amounts to 2 – 3°; in another place,† in discussing the reliability of their newer measurements at high temperatures, they state that there is a difference amounting to 5° between the older (1900) and the newer (1906) Reichsanstalt determinations at 1100°, and continue: "The deviation from the mean would still fall within the limits of error of the earlier determinations. We consider it better, however, to attach greater weight to the former measurements, because the temperature gradient in the gas thermometer bulb was much smaller in the earlier measurements." This may well be, for they give figures‡ which show that in the 1906 determinations at 1124° there were differences of temperature from one point of the bulb to another of as much as 346 microvolts, or about 29°.

Summary.

In this note a new calibration curve for copper-constantan thermoelements, extending from 0° up to 360°, is given, together with a series of independent measurements of the temperature differences between the boiling-points of naphthalene (217·95°) and benzophenone (305·9°), on the one hand, and the freezing points of tin, bismuth, cadmium, and lead on the other. These measurements lead to the following values of the freezing points: Sn, 231·8°; Bi, 271·0°; Cd, 320·9°; Pb, 327·3°. The concordance of these values with those obtained by other measurements show that the thermoelement is not inferior to the resistance thermometer within this range of temperature (0 – 360°). Moreover, a comparison of the gas-thermometer determinations with the results obtained by means of those interpolation instruments (thermoelement, resistance thermometer, etc.), which measure not temperature independently but a well-defined physical property which changes continuously with the temperature, affords an excellent opportunity, *through this continuity*, for the discovery of inconsistencies in the gas thermometer measurements. The remarkable concordance of the present series of thermoelectric measurements and of the most extensive recent series of resistance thermometer measurements (Bureau of Standards), with the recent gas thermometer determinations made in this laboratory, serves, therefore, as an efficient and independent check upon the trustworthiness of the present gas thermometer scale between 0° and 1100°.

Geophysical Laboratory, Carnegie Institution of Washington,
Washington, D. C., March 20, 1912.

* Sitzungsber. Akad. Wiss. Berlin, xliv, 414, 1906.
† Ann. Physik, xxii, 19, 1907. ‡ Loc. cit., p. 8.

Art. XLV.—*Note on Measurements of Radio-activity by means of Alpha Rays*; by W. R. Barss.

It is a well known fact that in a gas ionized by α-particles a saturation current is obtained only when a much larger potential gradient is applied between the plates of the ionization chamber than is necessary when β- or X-rays are the ionizing agents. Bragg and Kleeman* showed that a current through a gas, ionized by α-particles, was still unsaturated when calculation showed that the number of ions lost by general recombination was small. The effect was ascribed to "Initial Recombination"; i.e., to some of the ions being but partially separated from their parent molecules by the action of the α-particles. In the absence of an external electric field these ions fall back on their parent molecules and are thus neutralized. An intense electric field is supposed to complete the separation of the ions and to produce saturation. On this hypothesis, lack of saturation would not depend on the size or shape of the ionization vessel and saturation would be more easily obtained under diminished pressure.

Kleeman† has shown that lack of saturation with weak ionization by α-particles is not due to diffusion of the ions, nor does it depend on the recombination coefficient. He has shown that "Initial Recombination" is very small in gases ionized by β-, γ- and X-rays; in other words, these ionizing agents effect a more complete separation of negative ions from their parent molecules.

Moulin‡ has proposed an explanation of the mechanism of ionization by α-particles as follows. The ions formed by the α-particles are not distributed uniformly throughout the gas, but each α-particle has, associated with it, a column of ions, the axis of the column being along the path of the particle. Lack of saturation is explained by recombination of ions of opposite sign within each column. This recombination between ions of the same column ought to exceed that which would be obtained for the same number of ions distributed throughout the volume of the gas. The amount of the recombination between ions of the same column should be much greater when the field is applied in a direction parallel to the direction of the column, than when it is applied in a direction perpendicular to it; for the parallel field would leave the columns intact, while the perpendicular field would break each column into two parts by

* Phil. Mag., xi, p. 466, 1906.
† Phil. Mag., xii, p. 273, 1906.
‡ Le Radium, May, 1908, p. 136.

separating the positive and negative ions. Hence the lack of saturation should be more apparent in the former case than in the latter. These facts were experimentally determined by Moulin. He obtained saturation for the parallel field at 1200 to 1500 volts per centimeter while for the perpendicular field only about 200 volts per centimeter were necessary.

Moulin concludes that general recombination within the columns (proportional to the square of the density of ionization within the columns) is so much greater than "Initial Recombination" that the latter is negligible in comparison.

Ionization by α-particles was further investigated by Wheelock;* among other results, he obtained the following. When an electric field is applied parallel to the path of the α-particle and therefore parallel to the axis of the column of ions, the column would not be broken up and the recombination occurring would be between ions belonging to the same column. Since each particle makes the same number of ions along its path, the density of ionization would be the same in any one column and therefore it would be expected that the ratio of currents obtained with sources of different intensities would be constant for different potential gradients applied. When the field is applied perpendicular to the column and when the source of ionization is small, very few columns would exist in the ionization vessel during the time required for the ions to be carried over to their respective electrodes. Hence there would be little chance for recombination between the columns, so that it would be expected that the ratio of currents obtained with sources of different intensities would be constant as in the case of the parallel field. When the field is perpendicular and the source of ionization is stronger, enough columns might exist between the electrodes at one time to make recombination possible, not only between ions of the same column but between those of different columns. In this case the ratio of currents obtained with different source intensities might not be constant because of the added recombination of ions of different columns.

Wheelock found that the ratio of the current produced by a more intense source of rays to that produced by a weaker source is constant for the parallel field; that it is approximately so for the perpendicular field when the sources are both weak, and that it increases slightly with the potential gradient applied when the sources are stronger. This is as would be expected if the ions formed by α-particles are arranged in columns.

When the gas is ionized by β- or X-rays it would not be expected that the ratio of currents obtained for different source

* This Journal, xxx, 238, 1910.

intensities would be constant. Here the ions are distributed throughout the volume of the gas, and general recombination, which depends upon the ionization density, i.e., upon the number of ions per cubic centimeter in the gas, would increase as the ionization itself is increased, unless a saturating field is applied.

In a great number of important investigations in the subject of radio-activity, it has been assumed that the quantity of radio-active material present was proportional to the ionization currents produced by the α-rays. In these experiments, electrical fields have been applied which would have been ample to cause saturation if the ionization had been produced by β- or X-rays, but which are now known to be quite inadequate to produce saturation when α-rays are employed. Results which have been obtained in this way are of fundamental importance in the theory of radio-active transformation. They include the determination of relative quantities of radio-active substances by the "Emanation Method" and the method of thin films, as well as nearly all the measurements of rates of decay of such substances. It is safe to say that in no case in which such measurements have been made with an electroscope, in air at atmospheric pressure, has a saturating potential been applied, or even very closely approached. The fact that a fairly consistent body of measurements and constants has been built up by many investigators, notwithstanding this apparent flaw in their experimental arrangements, shows that the considerations advanced above must have a considerable degree of validity. The object of the present experiments is to test this point specifically in the important case when the α-rays are produced by an emanation mixed with the ionized gas. In this case the sources of the rays are scattered through the gas and on the walls of the vessel, and the paths of the α-particles and their attending columns of ions extend in all directions; so that the geometrical complication is as great as it can well be.

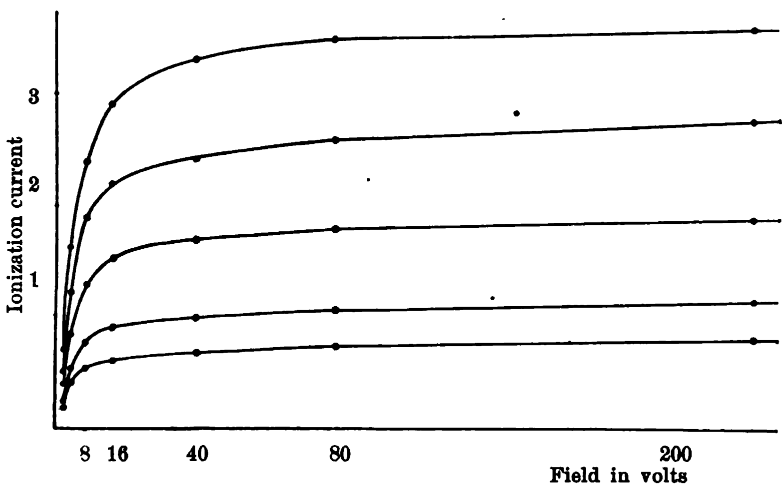
We might reasonably expect the ratio of currents to be constant in this case, at least for small source intensities. If the number of α-particles is small, there will be only a few columns of ions existing together during the time required for the ions to be carried to their respective electrodes. It is true that a portion of the α-particles will cross each other and that the separated columns of ions will also sometimes cross each other, thus producing some recombination between ions of different columns. But even when this happens, the crossing will usually be at an angle, and the length of each column is so great compared with the diameter of its cross section that even if they do intersect, the amount of this recombination will be neg-

ligible compared to the recombination between ions of the same column.

As the intensity of the source is increased, the number of columns of ions existing together is also increased. The probability that different columns will cross each other is greater and therefore the amount of recombination between ions of different columns will be greater. So that, as in the case of the perpendicular field, the ratio of the larger current to the smaller will probably increase as the potential gradient is increased.

In the present experiments, a cylindrical tin chamber was used $13{\cdot}5^{cm}$ high and $10{\cdot}5^{cm}$ in diameter. A central brass

FIG. 1.



electrode, provided with an earthed guard ring, was connected to a tilted electroscope of the Wilson type, the leaf of which was observed by means of a microscope having a graduated scale in the eyepiece. This central electrode and the leaf of the electroscope were grounded through a potentiometer by means of which each deflection due to the ionization current was calibrated in terms of potential. The capacity of the system was kept constant, so that these calibrated readings varied directly as the actual ionization currents. Different potentials were applied to the case of the chamber. Radium emanation was used as an ionizing agent; it has a half value period of about four days, so that it provided a suitable source of varying intensity.

One series of observed data is given in the following table V is the potential in volts applied to the case. C_1 represents the corresponding ionization current for a given intensity; C_2 the ionization current for a weaker intensity, etc.

V	C_1	C_2	C_3	C_4	C_5
2	·72	·55	·40	·23	·16
4	1·60	1·15	·85	·50	·38
8	2·50	1·90	1·40	·80	·55
16	2·90	2·20	1·50	·96	·65
40	3·35	2·40	1·75	1·05	·75
80	3·53	2·58	1·86	1·10	·78
200	3·65	2·80	1·95	1·16	·80
400	3·80	2·90	2·05		·83
600	3·90	3·00	2·08		

A series of curves plotted from these data is given in fig. 1: abscissæ represent the potential V applied to the case. Curve 1 has for its ordinates the values given in C_1 above, curve 2 the values in C_2, etc.

Ratios of ionization currents are given in the following table:

V	C_1/C_2	C_1/C_3	C_1/C_4	C_1/C_5
2	1·31	1·80	3·13	4·50
4	1·39	1·88	3·20	4·21
8	1·31	1·80	3·12	4·54
16	1·32	1·93	3·02	4·45
40	1·39	1·91	3·19	4·46
80	1·36	1·89	3·21	4·52
200	1·30	1·87	3·14	4·56
400	1·31	1·85		4·57
600	1·30	1·87		

It is evident that the current ratios are constant within the limits of experimental error.

In the above data the potential applied to the case was negative. A series of readings was made with the potential positive giving similar results.

The radium emanation used was drawn from carnotite, the amount of emanation being equivalent to the amount in equilibrium with about 10^{-8} gm. of radium. It remains to be tried to what degree the intensity may be increased before there is a change in the current ratios.

Summary.

When the *a*-particles are moving in all directions with respect to the electric field, and when the source of ionization is not too intense, the ratio of the currents obtained from two sources of different intensities is constant for different potentials applied to the ionization chamber.

No great errors are involved even when currents are used less than one-fifth of the saturation value.

In conclusion, I want to thank Professor Bumstead for his many suggestions throughout the experiment.

Sloane Physical Laboratory, Yale University, New Haven, Conn.

Art. XLVI.—*The Binary System: $Na_2Al_2Si_2O_8$ (Nephelite, Carnegieite)—$CaAl_2Si_2O_8$ (Anorthite)*; by N. L. Bowen.*

Contents:

Introduction.

The study of the system $Na_2Al_2Si_2O_8$—$CaAl_2Si_2O_8$ was undertaken because of the very considerable importance of these compounds as rock-forming constituents.

The compound $CaAl_2Si_2O_8$ occurs in nature as the mineral anorthite. The preparation of anorthite in the laboratory has been accomplished by a number of workers.

The compound $Na_2Al_2Si_2O_8$ ($NaAlSiO_4$) approximates in composition the natural mineral nephelite and has been prepared in a form resembling that of nephelite. It is mentioned in text-books of mineralogy as artificial soda-nephelite and is given a place in order to bring out the chemical relationship within the hexagonal group of which nephelite is the best known member.

Preparation of Materials.

In the preparation of mixtures for exact thermal work, it is important that only the purest material should be used. The calcium carbonate was of tested purity, the alumina was freed

* Presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Geology at the Massachusetts Institute of Technology; May, 1912.

from all but the last trace of alkalis by boiling with a solution of ammonium chloride and igniting. A very pure silica was obtained by grinding selected quartz and treating with hydrochloric acid. Anhydrous sodium carbonate was made from the hydrated compound by heating for eight hours at 300°C. It was proved that the material so obtained corresponded with the formula Na_2CO_3 by converting to chloride and weighing.

To make anorthite $CaCO_3$, Al_2O_3, and SiO_2 were mixed in the proper proportions and fused in a Fletcher gas furnace at about 1600°. Three fusions, the product being finely ground before each, gave a glass which crystallized to a perfectly homogeneous mass of anorthite.

In the preparation of the soda compound Na_2CO_3, Al_2O_3, and SiO_2 were mixed and the same procedure followed, but not with equal success. When the resultant glass was crystallized, instead of the homogeneous product to be expected, the microscope showed, scattered throughout, plates and needles of Al_2O_3 (corundum) uncombined. Repeated fusion did not remedy the difficulty. Finally, it was determined by analysis of the glass that some Na_2O had been volatilized at the high temperature of the gas furnace. The materials had been mixed in the proportion to give:—

	Na_2O	Al_2O_3	SiO_2		Sum
	21·77	35·89	42·34	=	100·00
Analysis showed	20·50	36·62	42·85	=	99·97

By heating the intimately mixed oxides at a low temperature (about 800°C) in an electric furnace, grinding and reheating four times, it was found possible to cause the oxides to combine without loss of soda. The whole could then be melted to a glass which gave on slow cooling a perfectly homogeneous crystalline mass with no excess of alumina.*

Even after combination some alumina develops in the perfectly homogeneous mass if held near its melting point for several days, from which it appears that some soda may still be lost after long heating. No very definite statements can be made concerning this phenomenon inasmuch as every effort was concentrated on its avoidance.

Preliminary Study.

A stock of the pure end members being ready, intermediate mixtures corresponding to each 10 per cent interval were made up.

* The loss of soda gave, of course, an excess in both silica and alumina. The silica undoubtedly went to form a small quantity of a more highly silicated compound, probably albite, which, however, did not appear as such and, therefore, must have disappeared in solid solution. Apparently no compound in which the ratio, $\frac{Al_2O_3}{Na_2O}$, is greater than unity could form under the existing conditions and the alumina was left free.

A preliminary study was carried out by putting some of each mixture in a separate platinum crystallizing dish and holding all at an approximately constant temperature in an electric furnace for a couple of days. The products were then examined under the microscope. This procedure was repeated at moderate temperature intervals over some range. The detail of this work need not be given here because it is not in itself of great importance, but is a very useful preliminary to the more precise determinations. It was noted that all compositions crystallize readily; that, in the mixtures, no reactions producing new components took place, leaving the system truly of two components. The existence of a eutectic point in the neighborhood of 1300° C. was indicated. Two different forms of the soda compound were observed, the one appearing at low and the other at higher temperatures. The low temperature form is analogous to nephelite and will henceforth, for convenience, be referred to simply as nephelite. The high temperature form had formerly been prepared at this laboratory, and given the name carnegieite. At low temperatures mixtures containing up to 30 per cent anorthite are perfectly homogeneous, showing the ability of the low temperature form to hold over 30 per cent of the anorthite molecule in solid solution. The lime compound was observed in only one form, anorthite.

Heating Curves.

With this preliminary information it was possible to proceed with the exact determination more expeditiously.

Small quantities of each mixture were crystallized at about 1200° C. (below the eutectic point indicated above), and heating curves run on each. The method employed was that found at the Geophysical laboratory to be the best in mineral work.[1]* The charge is of about 2 gms.; the bare thermocouple of platinum-platinum-rhodium dips into the charge and is connected with a potentiometer system which measures the E.M.F. set up at the thermocouple contact. A curve has been prepared giving the E.M.F. corresponding to temperatures between 0° and 1550° C. for standard elements calibrated against the gas thermometer. Such standard elements are used to calibrate the elements employed in the course of the work.

The furnace in which the charge is heated is an electrical resistance furnace in which a coil of platinum wire is the conducting material.

In running a heating curve the temperature of the furnace is caused to rise gradually and regularly. The temperature of the thermocouple in the charge is read at regular time inter-

* For references see list at end of article.

vals, and temperature is plotted against time. If there is no energy change within the charge, its temperature also rises regularly, but at the appearance of a new phase the rate of heating of the charge (the gradient of the heating curve) experiences a change depending upon the energy involved in the change of phase.

During the change of phase, on account of heat absorption, the temperature of the charge either remains constant or rises more slowly than the temperature of the furnace, but upon completion of the change of phase the temperature rises rapidly to that of the furnace. It is this sudden increase in the rate of heating of the charge which is commonly termed a 'break' on the heating curve. The temperature at which a break occurs is, then, the temperature at which the disappearance of a phase of the system is completed. In Table I the temperatures at which breaks were obtained on heating curves are given opposite the corresponding composition.

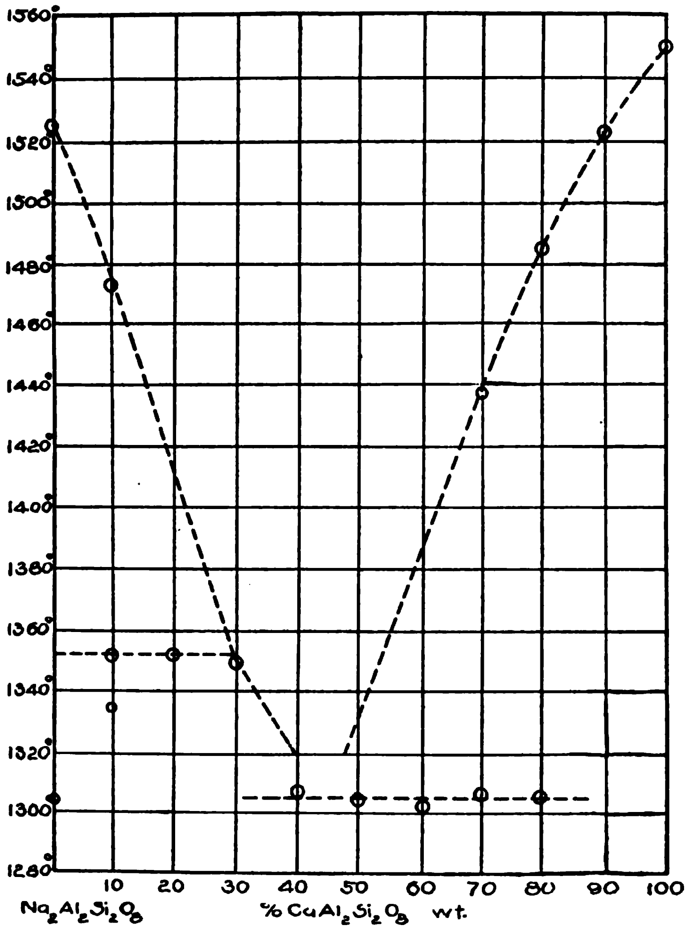
TABLE I.

Wt. % $CaAl_2Si_2O_8$	Upper point	Eutectic	Inversion	Knickpunkt
0	1527	....	1304	....
0	1525	....	1305	....
10	1473	....	1335	1352
10	....	....	....	1354
20	....	....	....	1360
20	....	....	....	1352
30	....	....	....	1349
40	....	1310°	....	....
50	....	1305	....	....
50	....	1304	....	....
60	....	1302	....	....
70	1437	1307	....	....
80	1484	1306	....	....
90	1522	....	....	....
100	1550	....	....	....
100	1549	....	....	....

These results are plotted on the temperature-composition diagram (Diagram I).

In the diagram each circle shows a temperature at which a break occurred on the heating curve for the corresponding composition. The general form of the equilibrium diagram is suggested. There is a eutectic point at about 1302°. Another triple point, possibly a 'knickpunkt,' occurs at about 1352°. The general form of the liquidus curves is indicated. Small heat effects obtained in the pure sodium compound and in the

DIAGRAM I.



mixture with 10 per cent $CaAl_2Si_2O_8$ are shown by small circles and are undoubtedly due to inversion.

Quenchings.

In Table I there are many blanks. Doubtless, some of these could have been filled in by especially careful work with heating curves, but a different method was adopted for obtaining the same informatiou.

The use of the quenching furnace[2] combined with the microscopic examination of the charges offers a trustworthy method

of obtaining information as to temperatures at which phases appear and disappear, and at the same time a knowledge of the nature of the phases themselves.

A small charge of any mixture, wrapped in platinum foil, is held at a definite temperature for a period of time which is deemed sufficient to insure equilibrium for that temperature and composition, and is then quenched by allowing it to fall into a dish of mercury at room temperature.

The chilling is so abrupt that any phase present at the furnace temperature is 'fixed' and ready to be studied under the microscope. By running a series of quenchings progress is made towards a knowledge of the phases present at equilibrium for each composition, at all temperatures—in short, towards the data necessary for an equilibrium diagram.

By the quenching method many changes of phase may be detected and studied which either take place too slowly or involve too little energy change to give an appreciable break on a heating curve. With many transformations, moreover, especially in the more viscous substances, superheating is likely to occur when the heating is rapid, as in running a heating curve, so that the actual break observed may come at a temperature higher than that at which the transformation concerned would take place if equilibrium prevailed. In quenching work it is the endeavor to make the time sufficiently long that all transformations which can take place at the temperature of the furnace may be complete.

In this work the thermoelement junction in the quenching furnace was distant from the charge 1/2 cm. or more. The small temperature difference between the charge and the furnace element was determined at frequent intervals over the temperature range desired by hanging a standard element in the position of the charge and reading both. The differences found were applied as corrections to the readings of the furnace element in the course of the work.

The furnace temperature was kept constant by noting it frequently and making the necessary changes in the resistance of the circuit. For the more careful work the current from a storage battery was used.

Several scores of quenchings were made. Of these, only the more significant will be tabulated (Table II), more especially those which determine the limit of stability for the various phases.

TABLE II.

(a) *Inversion.*

No.	Composition Wt. % $CaAl_2Si_2O_8$	Form at start	Temp.	Time	Phases found after quenching
1	0	Ne*	1245°	6 hrs.	Ne only
2	0	Ne	1252	1 hr.	Ne & Cg
3	0	Cg*	1245	1 hr.	Ne & Cg
4	0	Cg	1252	6 hrs.	Cg only
5	0	glass	1260	1 hr.	Cg only
6	0	glass	1252	1 hr.	Cg only
7	0	glass	1245	1 hr.	Ne & Cg
8	0	glass	1235	1 hr.	Ne & Cg
9	5	Ne	1260	4 hrs.	Ne only
10	5	Ne	1275	1 hr.	Ne & Cg
11	10	glass	1317	7 hrs.	Cg & Ne
12	10	Ne	1282	4 hrs.	Ne only
13	10	Ne	1294	1 hr.	Ne & Cg (trace)
14	10	Ne	1296	1 hr.	Ne & Cg

* Ne = Nephelite, Cg = Carnegieite.

(b) *Nephelite solidus.*

See also (solid solution An in Ne).

15	20	glass	1317°	6 hrs.	Ne only
16	20	Ne	1337	2 hrs.	Ne only
17	20	Ne	1340	1 hr.	Ne only
18	20	Ne	1343	1 hr.	Ne & glass
19	25	glass	1328	1 hr.	Ne & glass
20	25	glass	1322	1 hr.	Ne only
21	30	glass	1310	2 hrs.	Ne only
22	30	glass	1317	2 hrs.	Ne & glass

(c) *Ne liquidus.*

See also eutectic composition.

25	40	An & Ne	1320°	1 hr.	glass & Ne (bare trace)

(d) *Cg liquidus*

26	20	glass	1412°	1 hr.	glass & Cg (bare trace)
27	20	glass	1417	1 hr.	glass only
28	25	glass	1374	1 hr.	glass & Cg (rare)

(e) *An liquidus.*

30	50	An & Ne	1330°	1 hr.	glass only
31	60	An & Ne	1380	1 hr.	glass only
32	30	An & Ne	1392	1 hr.	glass only

(f) *Change of phase at 'Knickpunkt.'*

33	3	Ne	1357°	6 hrs.	Cg only
34	5	Ne	1357	6 hrs.	Cg & glass trace
35	10	Ne	1357	6 hrs.	Cg & glass
36	20	Ne	1357	6 hrs.	Cg & glass
37	30	Ne	1357	7 hrs.	glass only
38	3	Ne	1346	6 hrs.	Cg only
39	5	Ne	1346	6 hrs.	Cg & Ne
40	10	Ne	1346	6 hrs.	Cg & Ne
41	20	Ne	1346	6 hrs.	Ne & glass
42	30	Ne	1346	6 hrs.	glass & Ne

(g) *Eutectic composition.*

43	50	glass	1304°	2 hrs.	An & glass
44	40	glass	1304	2 hrs.	Ne & glass
45	47·5	glass	1304	2 hrs.	An & glass
46	46	glass	1304	1 hr.	An & glass
47	45	glass	1304	1 hr.	Ne & glass

(h) *Solid solution An in Ne.*

48	30	glass	1295°ca	2 days	Ne only
49	32	glass	1295°ca	2 days	Ne only
50	35	glass	1295°ca	2 days	Ne & An (mere trace)

(k) *Solid solution Ne in An.*

51	98·5	glass	1250°	2 days	An only
52	98	glass	1250	2 days	An & Ne (trace)
53	97	glass	1290	2 hrs.	An & Ne

(l) *Solid solution An in Cg.*

(See also change of phase at 'Knickpunkt.')

54	3	glass	1350°	6 hrs.	Cg only
55	5	glass	1350	6 hrs.	Cg & Ne (trace)

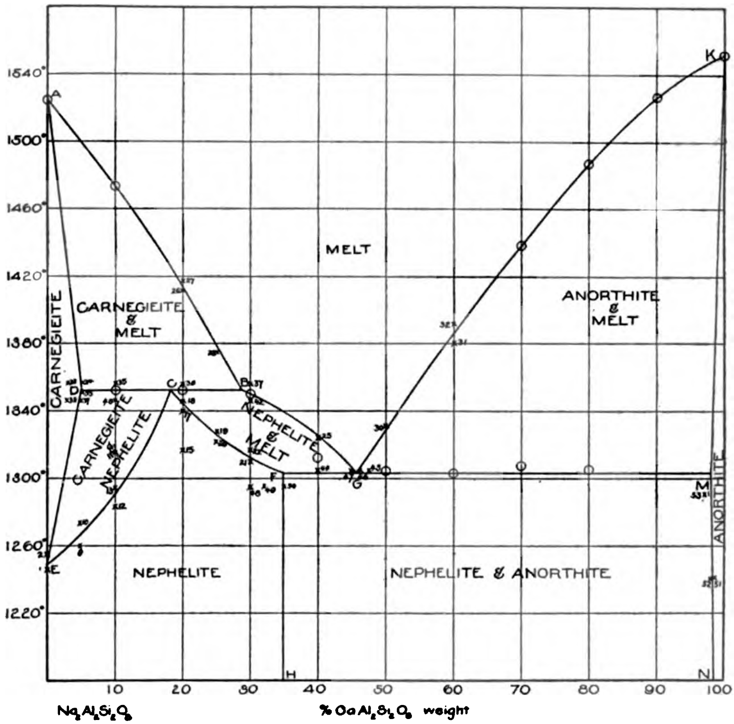
Many of these quenching results are worthy of special discussion, but this may be undertaken more profitably after they have been combined with the heating curve results and plotted on a temperature-composition diagram (Diagram II: Equilibrium Diagram).

Explanations of Signs and Terms.

In Diagram II the circles indicate heating curve breaks; the numbered crosses indicate temperatures and compositions at which quenchings were made, the numbers corresponding with those in Table II where the phases present are given. The data make possible the drawing in of the curves separating the fields of stability of the various phases. On each field the phases present at equilibrium are marked. Nephelite is used

to indicate the hexagonal form of $Na_2Al_2Si_2O_8$ and also the isomorphous hexagonal mix-crystals with 0–35 per cent $CaAl_2Si_2O_8$. Carnegieite is used to indicate the triclinic form of $Na_2Al_2Si_2O_8$ and also the isomorphous triclinic mix-crystals with 0–5 per cent $Ca_2Al_2Si_2O_8$. Anorthite indicates triclinic

Diagram II.



EQUILIBRIUM DIAGRAM.

$CaAl_2Si_2O_8$ and also the isomorphous triclinic mix-crystals with 0–2 per cent $Na_2Al_2Si_2O_8$.

Throughout the text abbreviations are used: Ne to indicate nephelite ($NaAlSiO_4$ hex.); Cg to indicate carnegieite $NaAlSiO_4$ triclinic); An to indicate anorthite ($CaAl_2Si_2O_8$ triclinic). Nephelite mix-crystals are indicated, $Ne_{65}An_{35}$ or Ne_{80}-An_{20}, the subscript numbers indicating the weight percentage of $NaAlSiO_4$ and of $CaAl_2Si_2O_8$ present in the mix-crystal. In like manner, carnegieite mix-crystals are referred to, –$Cg_{95}An_5$ and anorthite mix-crystal –$An_{98}Ne_2$. $NaAlSiO_4$ and $Na_2Al_2Si_2O_8$ are used interchangeably. The purpose in using the

latter form is that of bringing out clearly the analogy between the two components. No knowledge of the molecular weight is implied. Diagram II is the only diagram here contained on which certain points are lettered, and when these points are referred to by letter in the text, it has not always been considered necessary to specify Diagram II.

Discussion of Table II and Equilibrium Diagram.

Inversion Phenomena (*Table II* (*a*)).—In the heating curve work a break was obtained with nephelite (Ne) at 1305°. The heat effect was small and undoubtedly due to inversion. In the quenchings it was, however, found that nephelite will go over to carnegieite at a temperature considerably below 1305°. Held at 1245° for 6 hours there was no formation of carnegieite, but at 1252° for only one hour the charge was largely converted to carnegieite. These results indicate an inversion temperature between 1245° and 1252°. By starting with carnegieite (Cg) confirmatory results were obtained. Crystallized at a high temperature and then held at successively lower and lower temperatures, it was found that at 1252° no change took place in 6 hours, but that at 1245° partial conversion to nephelite was observed within one hour. From these results the inversion temperature is shown to lie between 1245° and 1252° or at 1248° (approx.). Close to the transition temperature the inversion is only partial in either direction, after several hours. At a temperature (about 1300°) more removed from the transition point nephelite is converted entirely to carnegieite within an hour. The reverse change does not proceed to completion so readily, but was effected by heating carnegieite over a Bunsen burner for 60 honrs.

Glass of composition $NaAlSiO_4$ crystallizes as carnegieite at any temperature above 1248°. At temperatures only a few degrees below 1248° where nephelite is the stable phase glass crystallizes as both nephelite and carnegieite, whereas nephelite itself shows no tendency to change to carnegieite at these temperatures. It seems possible that the unstable glass in assuming the stable form nephelite passes through the "less unstable" form carnegieite which may persist for a considerable time and is therefore found in the quenched products. Glass held at temperatures considerably below 1248° crystallizes only as nephelite. If the "less unstable" form, carnegieite, is formed at these temperatures it inverts quickly to nephelite.

With the nephelite mix-crystal ($Ne_{90}An_{10}$) a small heat effect suggestive of inversion was obtained at 1335°, somewhat higher than that in Ne. The results of quenchings indicate again

that this temperature is considerably higher than that at which inversion will take place if the time is sufficiently long. $Ne_{90}An_{10}$ may be held at 1282° (34° above the inversion point of Ne) for four hours without change. Held at 1294° for one hour a trace of the carnegieite form and at 1296° for one hour considerable carnegieite separates.

These results indicate that carnegieite first separates from $Ne_{90}An_{10}$ between 1282–1294° or at about 1290°. This rapid rise in the temperatures of inversion of nephelite as $CaAl_2Si_2O_8$ is taken into solid solution was confirmed in $Ne_{95}An_5$ (1265°) and in $Ne_{80}An_{20}$ which shows only the nephelite form at 1340°.

It is not possible to confirm these inversion temperatures by starting with the carnegieite form and studying the reverse change as was done with Ne and Cg because the behavior of these solid solutions is much less simple than that of the pure compound.

It is well known that according to theory a solid solution should, in general, melt, not at a definite temperature to form a liquid of its own composition, but that melting should be distributed over a temperature interval, the liquid first formed differing in composition (concentration) from the solid. Similarly the inversion of a solid solution takes place over an interval, the concentration in the first small quantity of the new crystal form being either greater or less than that in the old. It is mainly in these characteristics that a solid solution differs from a definite compound.

Both melting interval and inversion interval are exhibited by the nephelite solid solutions. Any point on the curve E C represents the temperature of the lower limit of the inversion interval for the corresponding composition and was located, as has been described by holding nephelite of that composition at higher and higher temperatures until evidence of inversion to carnegieite was obtained. Any point on the curve E D represents the temperature of the upper limit of the inversion interval for the corresponding composition. Only the end points E and D are accurately located and the middle portion qualitatively indicated (Table II (f) and (l)).

The concentration of $CaAl_2Si_2O_8$ in the carnegieite solid solution (E D) is much less than that in the nephelite solid solution (E C) in equilibrium with it at any temperature. Beckman[9] has developed an equation for the amount of change in the inversion (or melting) point of a substance by the solution in it of another substance. It reads $\Delta T = \frac{02T^2}{l}(C_2 - C_1)$ where $\Delta T =$ change in inversion temperature, T= absolute temperature of the inversion point in the pure substance, l=its heat of transformation, C_1= concentration of the solution above the inver-

sion point and C_2 = concentration of the solution below. In the present case, as has been stated, the concentration below the inversion point (nephelite) is much greater than that above (carnegieite), therefore $C_2 - C_1$ is *positive* and relatively large and so also Δ T. This corresponds well with the sharp *rise* in the inversion temperature of nephelite occasioned by the solid solution of $CaAl_2Si_2O_8$. Qualitatively, the facts fill the requirements of thermo-dynamic theory.

The Nephelite Solidus and Liquidus (*Table II* (*b*) *and* (*c*)).—The melting-interval of the nephelite solid solutions has already been mentioned. The solidus C F and the liquidus B G have the same significance in this connection as have E C and E D with respect to the inversion interval.

In mineral work it is not possible to locate solidus and liquidus by the method of separating solid and liquid phases from an equilibrium mixture at various temperatures and determining the composition of each phase. The solidus was located by finding the temperature at which nephelite mix-crystals of different compositions first showed signs of melting and the liquidus by finding the temperature at which melting was barely completed. After location of the curves in this manner the composition of liquid and solid in equilibrium with each other at various temperatures can be predicted with the degree of accuracy attained in the location.

The "Knickpunkt" (*Table II* (*f*)).—Breaks were obtained on some of the heating curves at 1352° (approx.). Quenchings show that this is the temperature at which the two solid phases, carnegieite and nephelite, are in equilibrium with liquid. The carnegieite has the composition $Cg_{95}An_5$(D), nephelite $Ne_{82}An_{18}$(C) and the liquid has 28·5 per cent $CaAl_2Si_2O_8$(B), the compositions being known from the positions of these points determined by quenchings and not from analysis (Table II (a), (b), (c) and (l)).

The Eutectic (*Table II* (*g*)).—Breaks were obtained on many of the heating curves at 1302° (approx.). Quenchings proved that at this temperature nephelite ($Ne_{65}An_{35}$) and anorthite ($An_{98}Ne_2$) are in equilibrium with a liquid with 45·5 per cent $CaAl_2Si_2O_8$ (eutectic). The exact composition of the eutectic mixture was obtained by holding the furnace slightly above the eutectic point and hanging in it four or five charges of the same mixture, one above another, on a platinum wire. The charge at one end of the wire is in the hottest part of the furnace a few degrees above the eutectic temperature and for compositions close to the eutectic is completely molten. The one at the other end is in a cooler part of the furnace a few degrees below the eutectic and completely crystalline. One or more of the intermediate charges is at a temperature only very

slightly above the eutectic point and will show on quenching the excess phase. By examining all, the excess phase for the composition used will be determined, and by repeating with other mixtures the eutectic may be placed within narrow limits. In this manner it was shown that in the mixture with 45 per cent $CaAl_2Si_2O_8$ nephelite was the excess phase, and with 46 per cent, anorthite. The eutectic composition is, therefore, between the two, approximately at 45 per cent $CaAl_2Si_2O_8$.

The Limits of Solid Solution (*Table II* (*h*) (*k*) & (*l*).—A solution may be defined simply as a homogeneous mixture, and with this in mind it is readily seen that the limit of solid solution might be determined by finding the first composition (concentration) which shows any trace of inhomogeneity. This method is, as a rule, the best in mineral work. The most important solid solutions encountered in this system are the nephelite mix-crystals. At a temperature slightly below the eutectic point the first mixture which showed anorthite in excess was that with 35 per cent $CaAl_2Si_2O_8$; in this the anorthite was a mere trace. The extreme solid solution is, therefore, approximately $Ne_{65}An_{35}$.

The maximum concentration of $CaAl_2Si_2O_8$ in carnegieite is obtained at the temperature of the 'knickpunkt' 1352°, where the composition of the carnegieite mix-crystals is $Cg_{95}An_5$ (approx.).

The Liquidus of Anorthite (*Table II* (*e*)).—The upper portion of the anorthite liquidus was established by heating-curve breaks. With lesser concentration of anorthite the magnitude of the eutectic break obscured the upper point, and in these mixtures the liquidus was located by quenching from various temperatures and finding that temperature at which the last trace of anorthite melted.

In a similar manner part of the carnegieite liquidus was located (Table II (d)).

Optical Study.

In the microscopic examination of the product of each experiment the method employed for identifying constituents was that of determining refractive indices in the crushed grains by immersion in liquids of known refractive index. This method is especially useful for detecting small quantities of any component. If the preparation be placed in a liquid which matches the mean index of the excess constituent, even very minute quantities of another constituent show up markedly, except in the rare case of different substances with nearly identical refractive indices. Moreover, it is possible to determine in the crushed grains most of the properties by which minerals are identified in thin section, such as order of birefringence, optical character, etc.

Anorthite.

The optical properties of anorthite (An) had previously been determined in detail at the Geophysical laboratory by H. E. Merwin, and the figures given are the results of his work.

$$\alpha = 1{\cdot}576,\ \gamma = 1{\cdot}589,\ \gamma - \alpha = {\cdot}013. \quad 2V - 80° \pm 3°$$
$$\beta = 1{\cdot}583,\ G = 2{\cdot}765.$$

Carnegieite.

Carnegieite (Cg) always shows polysynthetic twinning similar to that in albite, with high extinction, up to 36°, against the twinning lines. Other less persistent twinning lamellæ appear crossing these at various angles, often giving a microcline-like structure. On account of the universal intricate twinning, many of the optical properties are difficult of determination. The indices, obtained by matching with a liquid in sodium light and determining the index of the liquid on the Abbé refractometer, gave

$$\gamma = 1{\cdot}514,\ \alpha = 1{\cdot}509,\ \gamma - \alpha = {\cdot}005$$

The mean index is therefore low, comparable with that of leucite. The birefringence, measured with the compensating quartz wedge,* gave ·0052 and ·0048 in different plates. Optical character negative, 2 V small estimated at 12°–15°, probably triclinic.

All efforts to obtain euhedral crystals failed. In all charges showing carnegieite and glass (area A D B, Diagram II) the carnegieite is always in rounded crystalline globules. An attempt to grow crystals in a flux gave nothing but similar globules.

The density of crystalline carnegieite (Cg) is 2·513 at 21°, determined in Thoulet's solution on carefully selected material, free from air bubbles.

Nephelite.

In all charges consisting of nephelite and glass (area C B G F, Diagram II), the nephelite appears under the microscope in perfect hexagonal basal sections, dark with crossed nicols, or rectangular prismatic sections with parallel extinction, indicating the hexagonal nature of these mix-crystals.

Of the pure sodium compound, nephelite, euhedral crystals were prepared in sodium tungstate over a Bunsen burner. These were in all cases bounded by the prism and terminated only by the base. One of these was measured on the two-circle reflecting goniometer and the hexagonal nature confirmed. The maximum deviation from 60° of the measured prism angle was 16′, and the average deviation 8′, with fair to

good signals. The indices, determined by the immersion method in sodium light, gave $\omega = 1{\cdot}537$, $\epsilon = 1{\cdot}533$. Birefringence ·004, slightly, but noticeably less than that in carnegieite.

About half a gram of these crystals was tested for tungstic acid by boiling with hydrochloric acid. Only pure white silica was left with no yellow tinge. The amount of tungstic acid could not have been more than a trace.

The density of these crystals is 2·619 at 21°. The degree of correspondence of the artificial compound with the natural mineral is shown in the following table:

	Cryst'n.	Opt. Char.	ω	ϵ	G	habit
$NaAlSiO_4$ (artif.)	hex	neg	1·537	1·533	2·619	prism and base
Nephelite (nat.)	hex	neg	1·541	1·537	255–265	prism and base (predominant)

It may be fortuitous that there is close correspondence with Gladstone's law in the relation between the mean indices and densities of the two forms of the soda compound, but the fact is, perhaps, worthy of note. Gladstone's law states that the specific refractive energy $\frac{n-1}{d}$ is constant, whatever the state of molecular aggregation.

We have then

$$\text{for carnegieite} \ldots\ldots\ \frac{1{\cdot}512-1}{2{\cdot}513} = {\cdot}2037$$

$$\text{for nephelite} \ldots\ldots\ \frac{1{\cdot}535-1}{2{\cdot}619} = {\cdot}2042$$

Nephelite Mix-Crystals.

It was found possible to determine definitely the variation, with composition, of the optical properties of the hexagonal mix-crystals or solid solutions from Ne to $Ne_{65}An_{35}$. With increasing proportion of the lime molecule, the birefringence of ·004 (negative) grows less, passes through zero and finally becomes ·002 (positive).

The indices were determined in sodium light at room temperature by the immersion method. The results are shown in Table III and in the plot Diagram III, in which the size of the circles is a rough measure of the accuracy of the determinations.

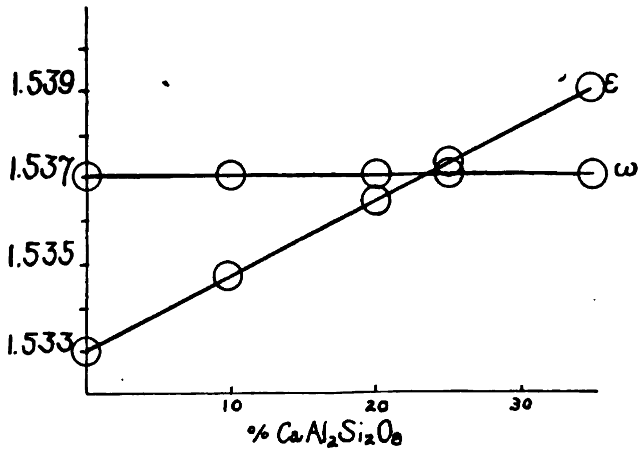
TABLE III.

Indices of Refraction of Nephelite Mix-crystals.

% $CaAl_2Si_2O_8$	ω	ε	Birefringence	Optical character
0	1·537	1·533	·004	—
10	1·537	1·535	·002	—
20	1·537	1·537—	very weak	—
23	1·537	1·537	none	isotropic
25	1·537	1·537+	very weak	+
35	1·537	1·539	·002	+

It will be noted that the refractive index of the ordinary ray remains sensibly constant, while that of the extraordinary ray mounts from 1·533 to 1·539. At the composition $Ne_{77}An_{23}$

DIAGRAM III.



(approx.) we have the unique case of hexagonal crystals isotropic with respect to sodium light.

Two different kinds of material were available for these determinations: homogeneous crystalline aggregates prepared by crystallizing the various compositions at about 1200° (area E C F H, Diagram II) and euhedral crystals $Ne_{81}An_{19}$–$Ne_{65}An_{35}$ embedded in glass obtained from quenchings within the area C B G F, Diagram II. With the former material the optical character of nephelite (Ne) was determined as negative and that of nephelite ($Ne_{65}An_{35}$) as positive by the ordinary interference figure method. With the latter material the optical character could be determined where the birefringence was extremely small because the relation of indices to crystallographic directions was known. Important aid was thus given

in determining the refractive indices; for example, both indices of crystals varying in composition from $Ne_{80}An_{20}$ to $Ne_{75}An_{25}$ appear to match the 1·537 liquid, but $Ne_{80}An_{20}$ is weakly birefracting and determinable in the prismatic section of a crystal as definitely negative and therefore $\omega > \epsilon$. In a similar manner it was shown that $Ne_{75}An_{25}$ is positive and therefore $\epsilon > \omega$. The positive character of crystals $Ne_{65}An_{35}$ indicated by the interference figure was confirmed in these crystals of known orientation.

A curious fact which gave rise to some difficulty in some of the quenchings may be noted here. The nephelite mix-crystals with 23 per cent $CaAl_2Si_2O_8$ (approx.) are in equilibrium at 1335° with a melt containing 36 per cent $CaAl_2Si_2O_8$ (approx). (Area C B F G, Diagram II.) When quenched the crystals are sensibly isotropic and have an index 1·537 and the glass, it so happens, has the same index.* Neither by a difference of index nor by the presence of birefringence do the crystals become distinguishable from the glass. Thus, in several charges quenched from 1335° the presence of nephelite in the glass could not be detected, although the necessity of its presence could be proven from charges quenched at a slightly higher or lower temperature, in which charges the extreme similarity of nephelite with the glass was approached, but not quite attained. For this reason the attempt to accurately locate the intersection of the liquidus B G on the ordinate of 35 per cent $CaAl_2Si_2O_8$ failed. The curve may, however, be regarded as sufficiently established by the other known points.

The Work of Earlier Investigators.

Several different workers have succeeded in preparing the nephelite form of $NaAlSiO_4$, but the carnegieite form has seldom been encountered. This is rather a curious fact, for carnegieite crystallizes readily from the pure melt, whereas nephelite is obtained only with very slow cooling† or with the aid of fluxes. Carnegieite was first prepared by Thugutt[7] by fusing an artificial 'nepheline hydrate.' He obtained a mineral with polysynthetic twinning and high extinction angles, probably triclinic. Following the suggestion of Lemberg, this mineral was called soda-anorthite.

In 1905, carnegieite was prepared at the Geophysical laboratory and the new name proposed. (Published 1910.)[8] But

*The index of this glass corresponds approximately with that calculated for it from the indices of anorthite glass and carnegieite glass in the proportion 36 : 64.

† With slow cooling, the temperature of the preparation is for a long period in the region slightly below the inversion point, permitting the formation of the low temperature form, nephelite.

few thermal determinations were made, so that its melting point and its relation to nephelite were not ascertained. It was not known at that time that some soda might be volatilized during the preparation of the compound, but a reëxamination of some of the samples then made gives evidence that there is a slight shortage in soda demonstrated by a slight excess of alumina. The optical properties of this material vary slightly from those of the purer material, since prepared, the figures for which are given here. For the same reason the density 2·513 found here is probably more accurate than that formerly found (2·571).

Gerh. Stein,[9] by crystallizing "soda-nepheline" directly from the melt, obtained a granular, *strongly* double-refracting mass. It is possible that Stein obtained carnegieite, of which the double refraction, though hardly strong, as ordinarily understood, is higher than that of nephelite.

Nephelite.—The formation of soda-nephelite was first accomplished by Fouqué and Lévy in 1878 by simple fusion of its constituents. With the addition of a flux (sodium vanadate) Hautefeuille (1880) succeeded in making measureable hexagonal crystals.[11]

In 1884 Doelter[12] prepared not only the simple orthosilicate, $NaAlSiO_4$ but mixtures with excess silica and the potash and lime content of natural nephelite.

Many others have succeeded in making nephelite as one constituent of a complex mixture, or by the action of aqueous carbonate solutions on various compounds. This work has no special interest from the point of view of this paper, and will merely be referred to here.

Doelter found that $Na_2Al_2Si_2O_8$ ($NaAlSiO_4$) and $CaAl_2Si_2O_8$ were capable of forming mix-crystals, as did the present writer. It appears that Doelter found a somewhat greater range of miscibility.

Wallace,[10] by the slow cooling of a melt of composition $NaAl SiO_4$, obtained a completely crystalline mass with low refractive index and low birefringence which he refers to as soda-nephelite. At the same time it should be noted that Wallace observed in thin section a microline-like structure and since this is a structure charcteristic of carnegieite there can be no doubt that some carnegieite was present.

On account of the long time necessary to obtain complete inversion in the direction carnegieite-nephelite, it may be stated as more than probable that much of the material prepared by direct fusion and described as soda-nephelite in the literature has contained some carnegieite. A rough similarity in optical properties is the reason for the failure to differentiate the two. The method of identification by immersion in refractive liquids eliminates this possibility.

Wallace found that a mixture of composition $NaAlSiO_4$ was completely molten at 1350°. The writer finds that $NaAlSiO_4$ does not melt till a temperature of 1526° is attained, the actual figures obtained in two determinations being 1527° and 1525°, of which the figure given is the mean (Table I). Possibly Wallace approached the unstable equilibrium nephelite-melt on cooling.

An indistinct heat effect was obtained by Wallace on the cooling curve at 1260°. The writer found a small heat effect, due to inversion, on the heating curve at 1305°. Allen found a point at 1289°.* The diversity of results is due to the indefinite nature of heating-curve breaks representing a sluggish transformation involving no great heat effect. The determination by the method of quenching gave 1248° (approx.) for the inversion point (Table II).

Anorthite.—Anorthite, like nephelite, was first prepared in 1878 by Fouqué and Lévy[11] by simple fusion of its oxides. No special interest attaches to the numerous other preparations of this mineral.

The melting point of artificial anorthite is sufficiently sharp to be used by Day and Sosman[14] as a reference point (1550°) on the temperature scale. Brun[16] obtained by his very different method (calorimetric) 1544°–1562°.

Mixtures.—Schleimer[18] has made determinations of the melting 'points' of mixtures of anorthite and nephelite using natural minerals. His mixtures are of very different composition from those used in this investigation and the temperatures found need have no relation to those found here.

Application to Natural Minerals.

Anorthite.—Several natural anorthites approximate closely to the theoretical composition. The melting points of some of these have been determined. Brun,[16] working with Seger cones, and Douglas,[16] the latest worker with the meldometer, have obtained figures that differ comparatively little from the figure given by Day and Sosman for pure anorthite.

Anorthite from Idsu, Japan, 1490–1520° — Brun.
Anorthite " Mte. Somma, 1505° — Douglas.

Nephelite.—In a recent paper[24] the writer has shown that experimental results are in accord with Schaller's statement that natural nephelites may be regarded as solid solutions of the three molecules $NaAlSiO_4$, $KAlSiO_4$ and $NaAlSi_3O_8$.

Natural nephelites, then, differ considerably in composition from the compound $NaAlSiO_4$ used in this work and the

* Geophysical Laboratory, unpublished notes.

difference in thermal properties is correspondingly great. Thus it was found by the writer that nephelite from Magnet Cove quenched from 1370° gave only a clear glass and therefore melts at some temperature below 1370°. Moreover, Wright[8] has found that molten 'nephelite' (Magnet Cove) crystallizes directly as nephelite without first showing the carnegieite form. In this respect nephelite from Magnet Cove behaves like the artificial nephelites with 28·5–35 per cent $CaAl_2Si_2O_8$ in solid solution.

Nephelite Mix-Crystals.—The extreme nephelite mix-crystals with 35 per cent $CaAl_2Si_2O_8$ contain approximately 7 per cent CaO. The lime content of natural nephelites never approaches such an amount. In nature, however, nephelite never occurs in intimate association with pure anorthite, although very often it does occur with a plagioclase. A plagioclase is a solution of anorthite in albite just as the mix-crystals above referred to consist of a solution of anorthite in nephelite. When all three substances are present there is, theoretically, a definite distribution ratio of anorthite between albite and nephelite, this ratio being equal to the ratio of solubilities. Albite dissolves anorthite to an unlimited extent. Nephelite dissolves 35 per cent. We have

$$\frac{C_1}{C_2} = \qquad = K = \frac{1}{35/100} = 3 \text{ (approx.)}$$

where C_1 = concentration of anorthite in the plagioclase.
C_2 = concentration of anorthite in the nephelite.

Obviously only when $C_1 = 1$ (i. e. pure anorthite) will $C_2 = 35/100$. For every other plagioclase there corresponds a definite composition of nephelite in equilibrium with it and the concentration of anorthite in plagioclase is three times that in the nephelite. The natural minerals always contain important quantities of other molecules which introduce variations, and viscosity may be such as to inhibit equilibrium, but the distribution should probably be of the order indicated. The analysis of a nephelite from Vesuvius shows the highest lime percentage (2·20 per cent) (11 per cent $CaAl_2Si_2O_8$) of all analyses of that mineral that have been made with sufficient care to warrant their consideration.[20] This nephelite should be in equilibrium with a plagioclase of approximate composition Ab_2An_1.

Other Solid Solutions.—The zeolite, thomsonite, consists of $CaAl_2Si_2O_8$ with $Na_2Al_2Si_2O_8$ up to 50 per cent, and corresponds in composition with some of the writer's mixtures with the addition of water. If, as Zambonini[21] concludes from the result of experiments, thomsonite is not a definite hydrate, the

existence of anhydrous orthorhombic crystals of like composition is to be expected. The orthorhombic mineral barsowite may represent one of these anhydrous thomsonites. The best analyses of that mineral give it a composition close to that of anorthite, with some soda and small quantities of other oxides.

No orthorhombic mix-crystals were encountered in the present work, but it is quite possible that such a series may be capable of existence at low temperatures where changes are so slow as to be obtainable only with the efficient fluxes of nature.

That nephelite will hold 35 per cent anorthite in solid solution, whereas carnegieite, which, like anorthite, is triclinic, will hold at most 5 per cent, comes rather as a surprise. That miscibility in the solid state does not always follow from crystallographic similarity is, however, well exemplified in a number of cases.

The very limited solubility of $Na_2Al_2Si_2O_8$ in anorthite has some importance in the light of the Linosa feldspar of abnormal composition recently described by Washington and Wright.[8] These writers came to the decision that the composition of the feldspar might be written $Ab_8An_{10}Cg_1$. The writer has found that solid solution of Ne in anorthite extends only up to 2 per cent, while, if the explanation of the Linosa feldspar offered by Washington and Wright is correct, solid solution of Ne in the plagioclase Ab_8An_{10} extends to 5·5 per cent.

Carnegieite.—The mineral carnegieite has never been definitely identified in nature. Most natural nephelites probably crystallized as such, for, if formed by inversion from carnegieite, the crystals would be unlikely to show continuous orientation.

In order that carnegieite might occur in a rock it is necessary that its crystallization should have taken place at a temperature above that at which the crystal form would change to that of nephelite, otherwise nephelite would occur. The inversion temperature 1248° applies only to the pure compound $NaAlSiO_4$. The presence of other substances affects this inversion point only when those substances can be taken into solid solution by the nephelite or carnegieite. In this work the effect of anorthite has been determined, and is such that crystallization would have to occur at a temperature still higher than 1248° in order that carnegieite might form, the maximum raising being about 100°.

The effect of the other substances which nephelite is capable of holding in solid solution is, however, still unknown, but the evidence is that the aggregate effect is not sufficient to carry the inversion point below the temperature at which the crystal-

lization of nephelite from most rock magmas would begin, otherwise carnegieite would be common.

From certain magmas very rich in 'nephelite,' the crystallization of carnegieite might be expected, but even this statement needs qualification, for, as we have seen, some nephelite, viz. that from Magnet Cove, may crystallize from its own melt directly as nephelite.

E. Esch[32] describes an abnormal nephelite from the nephelinite of Etinde volcano in German Kamerun. This mineral shows inclined extinction and a complicated twinning and is biaxial. In these properties it agrees better with carnegieite than with nephelite. On the other hand, the crystal outline is like that of nephelite and the determined mean index, 1·5376, very close to that of nephelite, but such an index is not impossible in carnegieite with certain compounds in solid solution. The mineral may possibly be carnegieite, but no definite decision can be arrived at until the possibilities of solid solution in carnegieite have been further investigated. This single instance appears to be the only one in which a mineral whose properties suggest carnegieite has been described.

Thermometry.

In the fact of its non-appearance in nature, carnegieite is like a great many other allotropic forms of minerals that have been made in the laboratory. These modifications are, in nearly all cases, the high temperature forms and their absence constitutes one of the proofs of the prevailingly low temperatures of natural magmas during crystallization.

It is evident from the discussion in the preceding paragraph that care must be exercised in putting to use the inversion of nephelite on the geologic thermometer scale.[33]

Minerals of simple, definite composition, SiO_2, $CaSiO_3$, and others have definite inversion points and the limits of stability of each form give definite points on the scale. On the other hand, a mineral of variable composition has a temperature of inversion which varies conjointly. With known composition, however, it will be possible, when sufficient experimental data has accumulated, to set equally definite limits to its stability as is exemplified in the present case of nephelite with variable content of lime.

There is reason to believe, as has been pointed out, that natural nephelites first crystallized as such.

In the event of the discovery of carnegieite in a rock its crystallization above 1200°* could probably be asserted with but little fear of error.

* It is necessary to leave some margin for a possible lowering due to solid solution.

General.

It is encouraging to note the occurrence within the mineral kingdom of one of Roozeboom's theoretically possible types involving both solid solution and enantrotropism. Some little hope of the eventual discovery of general laws, applicable even to the complex mixtures known as magmas, is aroused. The accumulation of precise quantitative data is the means to this end.

In conclusion the writer desires to thank E. S. Shepherd and F. E. Wright of the Geophysical Laboratory for much help and advice throughout the course of the experimental work.

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Art. XLVII.—*A New Occurrence of Carnotite;** by Edgar T. Wherry.

Introduction.

The more or less definite bright yellow uranium-vanadium mineral known as carnotite has been heretofore observed at a number of points in western Colorado and eastern Utah,† and as an alteration product of "davidite," a rare-earth-bearing rutile, at "Radium Hill," South Australia.‡ The purpose of the present paper is to call attention to its occurrence near Mauch Chunk, Carbon County, Pennsylvania.

In Genth's Mineralogy of Pennsylvania§ autunite was stated to "have lately been found in a conglomerate from the neighborhood of Mauch Chunk," the exact locality being, however, unknown. Specimens labeled similarly are included in several of the old collections of Pennsylvania minerals, but a study of these and of a considerable quantity of material collected at what is probably the original locality, the eastern end of Mt. Pisgah, immediately north of the town of Mauch Chunk, has shown that the mineral in question is really to be classed as carnotite.

Although the locality was re-discovered, by accident, by the writer in 1908, and the nature of the mineral proved by qualitative tests, detailed study was deferred in the hope of obtaining more satisfactory material when opportunity should present itself for thorough examination of the deposit. As this hope has not been realized, in spite of exhaustive search, it was decided to proceed with analysis of the specimens on hand, and to publish an account of the occurrence.

General Description.

The mineral presents the form of an amorphous to minutely crystalline bright yellow coating or impregnation in a conglomerate, often penetrating cracks in the quartz pebbles. Microscopic examination shows it to be quite impure, containing much limonite and clayey matter, and even the most crystalline-looking specimens show only an occasional translucent rectangular flake, with straight extinction, suggesting the tetragonal or orthorhombic system.

* Presented at the Baltimore meeting of the A. A. A. S., 1908; abstract in Science, vol. xxix, p. 751, 1909.

† Hillebrand and Ransome, Bull. U. S. Geol. Survey, No. 262, pp. 9–31, 1905; Fleck and Haldane, Rept. State Bur. Mines, Colorado, 1905–06, pp. 47–115, 1907; Gale, Bull. U. S. Geol. Survey, No. 315, pp. 110–117, 1907; Bull. No. 340, pp. 256–262, 1908.

‡ Crook and Blake, Mineralogical Magazine, vol. xv, pp. 271–284, 1910.

§ Report B, 2nd Penna. Geol. Survey, p. 144, 1874.

Chemical Composition.

Material for analysis was obtained by scraping off the coating from a specimen of rather friable conglomerate, and contained accordingly considerable amounts of quartz, as well as some limonite and kaolin. As the yellow substance proved to be entirely soluble in dilute nitric acid, while the greater part of these impurities are insoluble, this seemed adequate for the purpose in hand. Uranium and vanadium were determined by the method of Campbell and Griffin,* which was first tested on known solutions of the metals and found to give very accurate results. Iron and calcium were obtained in the usual ways, water by loss on ignition, and potassium, by difference. Barium, lead, and phosphoric acid could not be detected with certainty; the strong radio-activity of the mineral indicates the presence of radium, although its amount is of course too small to be estimated, while lack of material also prevented establishment of the presence of helium.

The analytical results are given in the first column of the accompanying table, and the figures obtained by deducting the insoluble matter, iron oxide and water, and recalculating the remainder to 100 per cent, in the second. The iron is certainly present as limonite, and while a part of the water may belong to the carnotite, the amount in this form is indeterminate, so it is best disregarded in calculating the formula. The results are given in the first decimal place only because of the unsatisfactory character of the sample. Most of this work was carried out, under the direction of the writer, by Mr. J. S. Long of Lehigh University, to whom much credit is due for skilful handling of the problems presented.

Analysis and Ratios.

	1	2	Ratios		
V_2O_5	7·2	21·1	·116		1·00
UO_3	23·8	69·8	·243		2·09
Fe_2O_3	6·1	...			
CaO	1·5	4·4	·079	·129	1·11
K_2O (diff.)	[1·6]	4·7	·050		
H_2O	10·5	...			
Insoluble	49·3	...			
	100·0	100·0			

Without attempting to place undue confidence in these results, it cannot be denied that they show a tendency to approach a definite ratio, $(Ca,K_2)O.2UO_3.V_2O_5$, or (Ca,K_2)

* Jour. Ind. Eng. Chem., vol. i, pp. 661–665, 1909.

$(UO_2)_2(VO_4)_2$, which is identical with that indicated by the previous work on carnotite.* Hillebrand† has shown, to be sure, that different samples of the mineral from Colorado vary rather widely in composition, yet throughout his and the other published analyses the ratio 1 : 2 : 1 for the three oxides is continually indicated. This is shown by the following table, in which the analyses have been recalculated to 100 per cent after deducting, as probably foreign to the mineral, the iron and phosphoric acid and also the water, whose amount is so variable that its rôle is uncertain.

Analyses of Carnotite (Recalculated).

	1	2	3	4	5	6
V_2O_5	21·16	21·28	22·03	22·72	21·50	21·89
UO_3	67·41	66·85	65·44	64·72	64·70	65·48
$R''O$	....	....	4·59	4·12	4·73	5·86
R'_2O	11·43	11·87	7·94	8·44	9·07	6·77
	100·00	100·00	100·00	100·00	100·00	100·00

	7	8	9	10	Calculated	1 : 2 : 1
V_2O_5	21·85	23·05	23·2	21·1	22·44	21·34
UO_3	65·27	65·68	66·2	69·8	70·65	67·64
$R''O$	6·48	6·40	3·2	4·4	6·91	....
R'_2O	6·40	4·87	7·4	4·7	....	11·02
	100·00	100·00	100·0	100·0	100·00	100·00

1, 2, Colorado: Friedel and Cumenge, Bull. Soc. Franc. Min., vol. xxii, p. 26, 1899 and elsewhere; considerable R″O probably present but overlooked and weighed with the R'_2O (Hillebrand).
3–8. Colorado: Hillebrand, Bull. U. S. Geol. Survey, No. 262, p. 25, 1905.
9, South Australia: Crook and Blake, Min. Mag., vol. xv, p. 271, 1910.
10, Pennsylvania. The results of the present study.
Calculated, a, for R″ = Ca; b, for R′ = K.

The cause of the variations in these analyses is not altogether clear; but, after all, they are perhaps no greater than is to be expected in view of the non-homogenous character of the samples examined, and the difficulties of the analytical procedure. In any case the evident similarity of the material from the three widely separated localities justifies no other conclusion than that we are dealing with a definite mineral species, of the formula $(Ca,K_2)(UO_2)_2(VO_4)_2$.

This formula at once suggests relationship with the uranite or autunite group, the members of which contain, however, from 8 to 10 molecules of water of crystallization. The amount of water found in the various samples of carnotite

* Cf. Crook and Blake, loc. cit. † Loc. cit.

varies from none in the Australian to perhaps 6 molecules in the Pennsylvania mineral, but then it must be remembered that most of this material is amorphous, leaving the question open as to its possible water content when well crystallized. The mineral may therefore be provisionally admitted to that group, which, named according to Washington's suggestion* (with one modification, the retaining of -ite as a termination, which, in the writer's opinion, may be desirable, to avoid confusion with chemical terms), becomes :

Uranite Group.

$R''(UO_2)_2(R^vO_4)_2.8H_2O$; chiefly orthorhombic.

Autunite.....	Ca	$(UO_2)_2(PO_4)_2.8H_2O$.	Calcium phosphuranite
Uranospinite.	Ca	$(UO_2)_2(AsO_4)_2.8H_2O$.	" arsenuranite
Torbernite...	Cu	$(UO_2)_2(PO_4)_2.8H_2O$.	Copper phosphuranite
Zeunerite....	Cu	$(UO_2)_2(AsO_4)_2.8H_2O$.	" arsenuranite
Uranocircite..	Ba	$(UO_2)_2(PO_4)_2.8H_2O$.	Barium phosphuranite
Carnotite	(Ca,K_2)	$(UO_2)_2(VO_4)_2.XH_2O$.	Calcium-potassium vanaduranite

Geological Relations.

Mt. Pisgah, the ridge extending westward from the Lehigh River just north of the town of Mauch Chunk, represents a synclinal mass of the Pottsville formation, the great series of interbedded sandstones and conglomerates regarded as the lowest member of the Pennsylvanian, overlying the Mauch Chunk red shale, the top of the Mississipian.† The contact between these formations, as exposed in the cuts of the highway and electric railroad across the eastern end of the ridge, is not a sharp one, but shows interbedding of the two types of sediment through a thickness of at least 100 feet. In addition to the red shale, there are also small lenses of black shale in the midst of the conglomerates.

The carnotite occurs in scattered streaks and patches throughout the lower portion of the conglomerate, not extending far above the last red shale layer, although ledges of conglomerate continue to be exposed 600 feet farther to the summit of the ridge. As the road turns westward, gradually rising across the beds, the layer containing it can be followed to a distance of 2000 feet, but then disappears beneath the roadway, and no trace of the mineral could be found at the corresponding horizon where again exposed near Tamaqua, 10 miles further west. Although its distribution is quite irregular, it is certainly most

* This Journal, vol. xxxiii, pp. 137–151, 1912.

† For a full description of these formations see Stevenson, Bull. Geol. Soc. Amer., vol. xiv, pp. 15–96, 1903 ; vol. xv, pp. 37–210, 1904.

frequently met with in the vicinity of the masses of black shale, and in fact small nodules of it are occasionally found in the shale itself.

That it has been deposited in its present form by circulating surface waters is clear. It is often locally concentrated along the more porous beds, and streaks may be observed beneath cracks in the rock from which water trickles out during wet weather. But its source is apparently to be sought in these lenses of black shale.

These dark shales do not owe their color to carbon, as might be supposed at first sight, but, as shown by microscopic examination, chiefly to the presence of hornblende, biotite, and other silicates in a fine state of subdivision, yet, in part, in fairly fresh condition. They can best be accounted for as a result of the peculiar climatic conditions which, as pointed out by Barrell,* prevailed here during late Mississippian times.

Under ordinary conditions of weathering silicates are decomposed, and only silica, kaolin, and ferric oxide remain to enter into the formation of sedimentary deposits. But in arid climates disintegration in general exceeds decomposition, so that heaps of greatly broken up, but comparatively unaltered, minerals will accumulate, and, when a more or less sudden change to conditions of heavier rainfall sets in, considerable quantities of these undecomposed minerals may be carried down into places of accumulation of sediments. These dark shales are believed, then, to represent "black sand" streaks, which, by reason of their distinctive specific gravity, have accumulated at points where the flow of the streams was favorable.

The materials of this portion of the Pottsville conglomerate were evidently derived from the crystalline Highlands of Pennsylvania, New Jersey, and New York; for while white quartz makes up the majority of the pebbles, occasional pieces of banded gneiss, crystalline limestone, and serpentine, of types familiar in that region can be seen in the carnotite-bearing beds. It has been found by Hillebrand† that vanadium is an almost universal constituent of igneous rocks, including the metamorphics of this Highland region, and is largely contained in their dark silicates. Under ordinary conditions of weathering much of this vanadium is carried away in solution, so that the average sediments contain only one-fifth to one-tenth as much as the rocks from which they were derived. In the present instance, however, it would seem reasonable to expect the concentration of practically all of the vanadium in the black shales as a purely mechanical process. Analysis of several samples of these rocks showed amounts varying from 0·08

* Bull. Geol. Soc. Amer., vol. xviii, pp. 449–476, 1907.
† Bull. U. S. Geol. Survey No. 167, pp. 49–55, 1900.

to 0·21 per cent V_2O_5. These specimens were free from any visible admixture of carnotite, and that no microscopic inclusions of such a mineral were present was proved by the insolubility of the vanadium in nitric acid, as well as the absence of proportionate amounts of uranium, noted in the succeeding paragraph. This vanadium probably replaces other sesquioxides in the silicates;* and as the fine state of division of the latter renders them easily attacked by surface waters, oxidation of the vanadous compound and development of some secondary vanadate is the natural thing to expect.

Uranium is also present in the metamorphic rocks of the New York–Pennsylvania Highlands, as shown by the radioactivity† of several widespread minerals, such as allanite and zircon, as well as the occasional appearance of columbite, uraninite, etc. Because of analytical difficulties no attempts have been made to determine its proportion in these rocks as a whole, but it may perhaps mount into the hundredths per cent. On the disintegration of the rocks, as described above, the uranium-bearing minerals would, of course, be expected to accumulate in the black sand lenses, along with those carrying the vanadium. Chemical examination showed, however, only about 0·002 per cent of UO_3 to be present, an amount whose concentration by circulating waters seems rather unlikely. It is not impossible that some of the pebbles of the conglomerate may contain uranium minerals, but no definite evidence of this has been, or, in the nature of the case, is likely to be, obtained, so that the immediate source of the uranium entering into the carnotite remains obscure, although in the total absence of deep-seated vein phenomena there can be little question as to its ultimate derivation in some manner from the sediments.

The conclusion to be drawn from these studies is, then, that the development of the carnotite at this locality has been made possible by mechanical concentration of uranium and vanadium minerals originally distributed through large bodies of crystalline rocks, brought about by a sudden change from a dry to a moist climate. To claim an identical origin for the deposits in Colorado and Utah would be hazardous, yet the published descriptions show that they also occur in arenaceous formations overlying "Red Beds," and if similar climatic changes were responsible for the change in character of the sedimentation there, it is quite possible that the concentration of the constituents of the mineral has been brought about in the same manner.

Indeed, it may be permissible to suggest that the frequent

* Cf. Hillebrand, loc. cit.

† Wherry, Jour. Frank. Inst., vol. clxv, pp. 59–78, 1908.

association of these elements uranium and vanadium with coal, pointed out more particularly by Clarke,* has a similar significance. The upper portion of the Pottsville formation in the Mauch Chunk region contains interbedded coal seams, the development of which was certainly connected with the favorable stimulus to plant growth resulting from the same change of climate which made possible the formation of the carnotite. In general, even though the association is not a genetic one, it seems reasonable to expect that, whenever the period preceding that of coal formation has been so dry that dark silicates have been broken up and transported to the points where the coal flora is to develop without extensive decomposition, the elements uranium and vanadium may be looked for as constituents of the ash. Or, in other words, in their presence or absence, we may have a new method of throwing light on certain details of the climatic conditions of past geologic times.

Summary.

1. Carnotite has been discovered in a new locality, Mauch Chunk, Carbon County, Pennsylvania.

2. As it agrees in composition with material from Colorado and South Australia, and these agree among themselves better than has usually been supposed, carnotite is entitled to be classed as a distinct mineral species, with the formula $(Ca,K_2)(UO_2)_2(VO_4)_2$, belonging to the uranite group.

3. The vanadium and probably the uranium also have been extracted by circulating surface waters from black shales, which have been formed in the midst of conglomerates by mechanical concentration of dark minerals from the crystalline rocks to the south and east, following the change from arid to moist climatic conditions at the beginning of Pennsylvanian time.

4. As the Colorado deposits occur in a similar position, their origin may have been the same, and it is suggested that the frequent association of these elements with coal may also be connected with such a climatic change.

Lehigh University, South Bethlehem, Pa.,
February 26, 1912.

* Bull. U. S. Geol. Survey No. 491, pp. 672–678, 1911.

ART. XLVIII.—*The Age of the Cleveland Shale of Ohio;* by H. P. CUSHING.

Introduction.—In the February number of this Journal appeared an article entitled "Unconformity at the Base of the Chattanooga Shale in Kentucky." In addition to describing the unconformity, the author endeavors to fix its date and its duration, and this endeavor leads to a discussion of the age of certain rocks in Ohio with which I have some familiarity. The author also expresses his personal opinion of the correctness of the work of certain geologists, in part no longer living, and since I think that in one notable instance his judgment is at fault, I wish also to say a word concerning it.

That the Newberry Survey erred in correlating the Cleveland shale of northern Ohio with the Sunbury (Waverly black shale) of southern Ohio was but natural, and was later freely acknowledged by Dr. Newberry himself; the error of correlating the black shale along the lake shore west of Cleveland with the Huron shale he himself corrected later, as Mr. Kindle points out. But it seems to me that neither of these has the remotest connection with the argument given in the following quotation:

"When Prof. Newberry found himself unable to substantiate his previously published statement of the occurrence of a Waverly fauna at the base of the Cleveland shale, he continued to maintain the Carboniferous age of the formation chiefly on the evidence of the occurrence in it of three genera of Carboniferous fishes, namely, Hoplonchus, Orodus, and Polyrhizodus.* Concerning this evidence it is well to recall that most of the fossil fishes described by Newberry were obtained for him by collectors on whom he depended for the correct designation of their geologic horizon. Since Prof. Newberry had himself confused the Sunbury and Cleveland shales, the opportunities which existed for the collectors to confuse them are too evident to require discussion." †

Now, leaving wholly aside the question as to the accuracy of the work of the group of excellent geologists who constituted the corps of the Second Geological Survey, what I wish to point out is that there was practically no opportunity for confusion of these two formations, in so far as these three genera of fishes were concerned. All three are described from the Cleveland shale at Bedford.‡ Because the Cleveland and Sunbury were confused in a long-range correlation the full width of the State, is far from making it "too evident to require discussion" that the two were confused at a single

* Mon. xvi, U. S. G. S., p. 123.
† This Journal. Feb. 1912, p. 132.
‡ Geol. Surv. Ohio, Pal., vol. ii, pp. 50, 51, 55.

locality. There is no real Sunbury in the section at Bedford, the horizon being occupied by a few feet of light-colored shale. Above this there is a blackish shale, the Orangeville, but the merest tyro in geology could not confuse this with the Cleveland when one considers the prominence of the Berea grit in that uninterrupted section. But the matter is finally settled for us by Newberry's definite pronouncement that he collected these fossils *himself;* he says: "At Bedford I obtained from this stratum quite a number of fish-teeth consisting of species of *Polyrhizodus*, *Cladodus*, and *Orodus;* all Carboniferous sharks." *

Aside from the frequent tiny scales of Paleoniscus (?) remains of fishes are rare fossils in the Cleveland shale. The local collector, he who diligently scans his ledges day after day throughout the year, can make collections at some localities. But the geologist, spending a day or two at a locality and then moving on, is exceedingly fortunate if he finds in that time any fish remains whatever worth taking along. Under these circumstances the fact that subsequent collectors have failed to report these forms from the Cleveland shale is not so surprising as it might seem. Some years ago, however, I collected from the Cleveland shale at Bedford a fragment of a spine, which tends to substantiate Newberry's assertion.

Age of the Cleveland Shale.—I have had in manuscript for some time a report on the geology of three quadrangles in the Cleveland vicinity, the result of recent field work. Earlier work had given me a familiarity with the formations concerned all across northern Ohio. In two respects this work has a bearing on the problem discussed by Mr. Kindle, and these I wish briefly to set forth.

Shales west of Cleveland—At Cleveland the Cleveland shale is a band of black, slaty shale, 20 to 50 feet thick, which is most sharply delimited from the underlying Chagrin shale and the overlying Bedford shale. The same conditions persist east of the city. But in West Cleveland the true Cleveland shale is underlaid by from 15 to 20 feet of blackish soft shale, with thin bands of blue shale, which separates it from the Chagrin below. This is well exposed along Big Creek. A few miles farther west, along Rocky river, this blackish shale has increased to 60 feet in thickness, and the steady increase in thickness seems to continue to the west edge of the Berea quadrangle, beyond which our detailed work has not gone. This increasing thickness, coupled with a westerly dip, puts the Chagrin summit below the lake level at Avon Point.

Now this blackish shale must be one of three things: it may represent a lateral change in character of the Chagrin shale; it may represent a downward thickening of the Cleveland shale,

* Geol. Surv. Ohio, vol. i, p. 189.

as Newberry finally regarded it; or it may represent a different formation from either. The Chagrin overlapped on the region from the east; the Cleveland came in from the south and pinches out to the east; and it seems as though this blackish shale did likewise; it increases in thickness westward so far as we have carried it, and it wedges out at Cleveland. Its rate of overlap is much more rapid than that of the Cleveland, which is the chief reason for my present disposition to regard it as a separate formation, separated from the Cleveland by a small break, rather than as a lower, overlapping portion of the Cleveland. That it is a separate formation from, and has nothing to do with, the Chagrin I feel reasonably sure. But I am far from claiming that the matter is settled one way or the other. Though much like the Cleveland lithologically, it can be distinguished from it; and since it is wholly absent from the type sections of the Cleveland shale, I am calling it the Olmsted shale, from the excellent exposures of it along Rocky river.

Unless I greatly mistake, the large collections of fishes which have been made in Lorain county have come from this Olmsted shale, not from the true Cleveland. Certainly this is true of the collections from the lake shore. And in any case this is the shale which Newberry called Huron in the Ohio reports, and re-identified as Cleveland in Monograph xvi.

Now the point of all this is, does this blackish Olmsted shale keep on increasing in thickness westward, and what thickness does it finally attain? *And what is its thickness along the Huron river?* This is the type locality of the Huron shale. At Cleveland the drill shows a thickness of 1200 feet of shale, Chagrin and so-called Huron, between the Cleveland shale and the Devonian limestones. At Lorain, 25 miles west of Cleveland, there remains less than 700 feet (probably not over 600) of this thickness between the Olmsted shale and the limestone. If the same rate of disappearance by overlap continues, there will not be much of this shale series left by the time the Huron river is reached. How much, then, of the so-called Huron shale in Lake county is real Huron, and how much is Olmsted? The former is older than the Chagrin shale, which is exposed at Cleveland, the latter probably younger and certainly not older. I cannot answer this question as yet. I merely know enough to suggest caution in regard to drawing any conclusions from the supposed age of the Huron shale at the type locality. I surmise that much of it is Olmsted: just as I surmise that much of the Ohio shale at Columbus is Olmsted. If so, many of the supposed Huron fishes may not be Huron fishes at all.

Shales east of Cleveland.—Passing east from Cleveland, the Cleveland shale runs for some 50 miles to the eastward and then seems to pinch out. It occurs on the west side of the

Grand river valley in Ashtabula county, but has not been found on the east side. The country there is, however, poorly adapted to furnish exposures of the proper horizon.

At the same time the Chagrin formation underneath increases in thickness eastward with great rapidity, and in its eastern extension fossils are much more abundant and range through a greater vertical thickness of the formation than is the case about Cleveland. In its upper portion also faunas seem to come in which are no longer typical Chemung faunas, but higher ones. I have, for example, collected abundant Syringothyris near Jefferson, at least 100 feet below the summit of the beds which were formerly referred to the "Erie" (now Chagrin) shale by Newberry. These upper faunas have not been diligently collected and studied, except perhaps very recently by Prosser. My impression is that there comes over into the eastern townships of Ohio a thinned and thinning edge of the formations which, in western New York and Pennsylvania, have been called the Oswayo and Knapp, or the Conewango and Knapp formations, and which are regarded as younger than the Chemung. So far as I know, these beds have not as yet been noted on the west side of Grand river, while the Cleveland shale has not been found on the east side. The Cleveland pinches out going east, the others toward the west. Until the district has been thoroughly covered in the effort to find the two in the same section, so that their relative ages may be determined beyond question, some doubt must attach to it. It seems to me to be most probable that the Cleveland overrides the other, and is the younger, in which case it can hardly be classed as Devonian in age. My reason for the belief is that, up to the point of its disappearance, the Cleveland sticks tightly to the base of the Bedford; and the Bedford overrides these other formations on the east side of the Grand river valley. But I most frankly admit that this is nothing but a surmise. I simply want to point it out as a possibility, and to urge it as the most promising method of settling what the age of the Cleveland shale really is. But until it is shown that the Cleveland does not override these formations, the conditions seem to me to strongly suggest caution in asserting the Devonian age of the Cleveland shale. Just as the conditions to the west of Cleveland seem to me to suggest caution in asserting that the whole, or even the greater part, of the Huron shale is older than the Chagrin.

In closing I wish to make one more suggestion, namely, that if the Conodont faunas of the Huron and Cleveland shales are to receive detailed study, it would add much to the importance and completeness of the results if the similar faunas of the Sunbury were included. I think no one questions the Waverlyan age of the Sunbury.

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SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Ultra-filtration in Chemical Analysis.*—Zsigmondy, Wilke-Dörfurt and Galecki have devised a method of analytical filtration which permits the collection of the most finely divided precipitates, and even of many colloidal substances where the particles are invisible, such as those of certain gold and ferric oxide "solutions." The method appears to be suitable also for removing turbidity in cases where ordinary filtration with paper is unavailing. To prepare these filters a film of collodion is first prepared by diluting 200^{cc} of 6 per cent collodion with 200^{cc} of ether and 500^{cc} of absolute alcohol, carefully pouring and spreading a film of this liquid upon plate-glass, waiting until most of the ether has evaporated and the collodion is no longer sticky, then plunging the whole into water. After 10 or 15 minutes the film may be separated from the glass and it may then be preserved under water for a long time. The sieve-like bottom of a porcelain filtering funnel is now provided with a piece of moistened ordinary ashless filter paper, then a piece of the collodion film is laid upon the paper in the funnel, suction is applied with a water-jet pump, and the filter is pressed a little against the sides of the funnel, so that the collodion filtering surface may be continuous and practically air-tight. Filtrations can now be made in the usual way with this filter, but the process is considerably slower than with paper alone. The authors have tested the method by collecting colloidal gold and ferric oxide and weighing the substances after ignition, both on the analytical balance and with Nernst's micro-balance. They have compared the weight of silver chloride filtered in this way, and with ordinary paper, with closely agreeing results. By collecting barium sulphates immediately after precipitation they have re-discovered the long-known fact that this substance forms supersaturated solutions and is not at once completely precipitated—*Berichte*, xlv, 579.

H. L. W.

2. *Magnesia Rods as a Substitute for Platinum Wire.*—E. Wadekind recommends the use of small magnesia rods, about 1^{mm} in diameter, for use in various blow-pipe tests. The best material for the rods is not pure magnesia, but the same mixture that is used for the supports of incandescent gas mantles. The rods serve well for producing flame colorations, as the mass itself after short ignition in the Bunsen flame gives no coloration. With the salts of the alkali-earth metals the flame-color is not as persistent with the rods as with platinum wire, but it is quite sufficient for ordinary qualitative tests. It is possible with the magnesia rods to produce much larger borax and salt of phosphorus beads than with platinum wire, a circumstance which is advantageous particularly in the test for silica. The colors of the

beads are especially striking on account of the white background furnished by the rod. Fusions for the manganese and chromium tests can be made very satisfactorily upon these rods. The rods serve well also in the place of asbestos fibers, for producing sublimates from the flame upon porcelain. The rods are stuck into a cork for use, and after using the end is broken off, so that beads and fusions may be preserved for reference. The cost of the rods, about 1^{mm} thick and 15^{cm} long, is 1 to $1\frac{1}{2}$ pfennig in Germany, so that there is considerable economy in their use as compared with platinum wire.—*Berichte*, xlv, 382. H. L. W.

3. *The Combustion of Carbon Monoxide.*—The combustion of carbon monoxide has been usually regarded as taking place according to the equation $2CO + O_2 = 2CO_2$. This equation does indeed express the final result, but it is known that the reaction is not a direct one, for Dixon has shown that traces of moisture are indispensable for the reaction even at high temperatures, and Remsen has found even at 300° ozone is incapable of oxidizing the gas. However, moist palladium-black, even at ordinary temperature, causes carbon monoxide and oxygen to combine. Traube has attempted to explain these facts by assuming an intermediate formation of hydrogen peroxide as follows:

$$CO + H_2O + O_2 = CO_2 + H_2O_2$$
$$CO + H_2O_2 = CO_2 + H_2O$$

Wieland now presents a new view of the matter. He has found that moist palladium-black, in *absence of oxygen*, causes the oxidation of carbon monoxide, apparently according to the equation $CO + H_2O = CO_2 + H_2$, and he has shown that a first product of the reaction is formic acid: $CO + H_2O = HCOOH$. Then, since palladium-black rapidly decomposes formic acid, as is well known, the final result is:

$$HCOOH = CO_2 + H_2 \text{ (combined with Pd).}$$

Wieland has been able to show further, that formic acid is produced also in the combustion of carbon monoxide at a high temperature, by directing the flame against ice and examining the resulting water. Therefore, it appears that the mechanism of the carbon monoxide combustion under all conditions consists in its combination with water and the splitting off of hydrogen from the resulting formic acid. In the presence of oxygen this hydrogen oxidizes at once to produce water for further reaction, and it is in this combination of hydrogen with oxygen that the traces of hydrogen peroxide observed by Traube are produced.—*Berichte*, xlv, 679. H. L. W.

4. *The Purity of Commercial Metals.*—F. Mylius has made analyses of a number of very pure metals obtained from Kahlbaum. Determinations were made of the metallic impurities by the use of samples of 100 grams or more. In most cases the analysis was facilitated by the fractional crystallization of a large part of the metal in the form of a pure salt which left the impurities in the mother-liquor. The zinc, cadmium, tin and lead each

contained less than 0·01 per cent of impurities, which is a very satisfactory result. The zinc and cadmium had been purified by distillation, the tin by electrolysis, and the lead by the reduction of a pure salt. The author classifies commercially pure metals into grades of purity, a maximum of 10 per cent impurity representing the first grade, while maxima of 1 per cent, 0·1 per cent, and 0·01 per cent represent the second, third and fourth grades, respectively. He remarks that technical products of the fourth grade, that is with less than 0·01 per cent of impurities, may be obtained at present in the cases of gold, silver, platinum, mercury, copper, tin, lead, cadmium and zinc. This does not take into account the possible presence of small amounts of oxygen in the more oxidizable metals.—*Zeitschr. analyt. Chem.*, lxxiv, 407.

H. L. W.

5. *The Effect of Temperature upon Radio-active Disintegration.*—That high temperature has no detectable influence on the intensity and nature of γ-rays from various radio-active substances has been conclusively demonstrated by the investigations of Bronson, Engler, Schmidt and others. Perhaps the severest test was that applied by Rutherford and Petavel, who showed that the γ-radiation from radium emanation exposed momentarily to a pressure of about 1200 atmospheres and a temperature at least as high as 2500° C., produced by an explosion of cordite, was not altered at the instant of explosion. A temporary reduction of 9 per cent in the activity, observed after the explosion, was due to a change of distribution of radium C within the bomb, caused by its volatilization and subsequent condensation, and was in complete agreement with the decrease calculated theoretically. On the other hand, the results obtained with β-rays have been very discordant, save in one respect, namely, that high temperature seems to have some effect on the emission of rays of this kind. Since the question is of great theoretical importance, it is worthy of note that the matter has been finally settled by the systematic investigation of ALEXANDER S. RUSSELL, who undertook the work at the request of Professor Rutherford.

The furnace used consisted of a silica tube $12·5^{cm}$ long, $2·2^{cm}$ internal diameter, open at both ends, and wound with a helix of platinum wire. The whole was jacketed with "Kieselguhr" for thermal insulation. The temperatures were measured with a platinum rhodium thermo-couple. A value of 1150° C. was easily attained but usually not exceeded. The radio-active materials studied were sealed in quartz tubes which were suspended centrally in the furnace by means of thin nickel wire. When thus mounted there was a clear path between every point of the tube and the lead electroscope, the distance being from 40 to 60^{cm}.

In the case of pure radium C, deposited on nickel by von Lerch's method, the decay of the radiations during three hours was measured, the containing quartz tube being maintained at 1150° C. for the first 90 minutes, and at room temperature for the rest of the time. The β-rays were studied over the entire inter-

val and the γ-rays only at the high temperature. This experiment agreed with subsequent tests in showing that neither the β- nor the γ-rays of radium C are affected by high temperatures. Under all conditions both radiations decayed exponentially, falling to half value in about 19·4 minutes.

Experiments with the active deposit gave the following results. The β-ray activity decayed at the theoretical rate both at 1150° C. and at 200° C., and the amount of activity was unaltered by the temperature changes. Of the 35 points determined, 2 were within 3 per cent, 2 within 2 per cent, and 31 were within 1 per cent of the theoretical values. In like manner, the γ-ray points fell on a smooth curve without abnormalities at the high temperatures ; 29 points agreed within 1 per cent with the theoretical values, and the remaining 4 points within 2·5 per cent.

The rest of the investigation deals with the volatilization of radium C inside quartz tubes, with experiments on the radium emanation, and with the partition of homogeneously distributed activity. The conclusions drawn by Russell from the entire research may now be quoted.

"(a) The effect of temperature upon the rate of decay, and the amount of β- and γ-ray activity, of radium emanation, active deposit, and radium C have been investigated." "The results are entirely negative."

"(b) Radium B and radium C, and very probably radium A, may be completely volatilised inside sealed quartz tubes at a temperature of 650°." "Radium B commences to volatilise at room temperatures."

"(c) All abnormalities of activity of β-rays obtained by previous authors, and by the author of this paper, can be completely explained on two simple grounds, a change of distribution and a change of partition, of radium C inside quartz tubes, produced by changes of temperature."—*Proc. Roy. Soc.*, lxxxvi, p. 240, Feb. 1912. H. S. U.

6. *Das magnetische Spektrum der β-Strahlen des Thoriums.*—The investigation of the β-rays from mesothorium 2 and its disintegration products has been successfully continued by VON BAEYER, HAHN and MEITNER. The advance is due primarily to an improved process of electrolytic deposition, devised by Meitner, which makes it possible to obtain very fine wires of higher activity and consequently to take much sharper photographs of the magnetic spectra than formerly.

A strong preparation of mesothorium, which had been freed from radio-thorium about a day earlier, was used in the electrolytic process. Only mesothorium 2 and a trace of the newly-formed radio-thorium were deposited on the silver cathode. The negatives were taken in the same manner as for the β-rays of radium (see this Journal, vol. xxxiii, page 281). In general, the deviating field amounted to 138 gauss. The time of exposure was one-half hour in the case of a wire which was 0·1^{mm} in diameter and which was covered with mesothorium 2 having an activ-

ity corresponding, by the γ-ray method, to 6 mg. of radium bromide. The negative shows six strong spectral lines, one (undeviated) for the α-ray pencil and five for the β-ray pencils. The line for the slowest β-rays is resolved into two distinct components, a fact which the earlier work did not bring out. A photograph taken with a stronger magnetic field showed two additional but weak lines, and this leads the authors to remark: "It is probable that, with stronger preparations and greater resolving power, the existence of still other weak β-rays could be demonstrated." On the other hand, the improved experimental conditions did not essentially change the continuity of the broad, diffuse band produced by the swifter β-rays.

Since, as is well known, mesothorium 2 has a half-value period of 6·2 hours, the authors thought that it ought to be possible to show photographically the growth of thorium X, thorium emanation, and the resulting active deposit. In order to test this point, a second exposure was made, 24 hours later, to the same active wire mentioned above. A new line, ascribed to thorium X, shows very distinctly on this negative, whereas the spectrum of mesothorium 2 is appreciably fainter. A third exposure of twelve hours duration was made eight days after the first. It contains no lines of mesothorium 2, it verifies the second negative, and it shows a second, less-deviated, fainter line of thorium X. Also, a still less deviated line of thorium A may be seen in the reproduction. The photographs of this set are scientifically beautiful and very instructive.

The second division of the paper deals with the β-rays from the active deposit of thorium. The details of this section will be passed over in order to quote the third division, in which are collected the latest results of this work. Mesothorium 2 gives rise to swift β-rays, exceeding 0·7 of the speed of light. In addition there are two weak lines corresponding to speeds of 0·66 and 0·60, and five strong β-ray pencils of speeds 0·57, 0·50, 0·43, 0·39, and 0·37. Thorium X gives 0·51 "weak" and 0·47 "strong." Thorium A gives 0·72 weak and 0·63 very strong. Th (B+C+D) has fast β-rays over 0·72 of $3\times10^{10}\ {}^{cm}/_{sec}$ together with 0·36 weak and 0·29 strong.—*Physikal. Ztschr.*, April 1, 1912. H. S. U.

7. *Applied Physics for Secondary Schools;* V. D. Hawkins. Pp. ix, 199. New York, 1912 (Longmans, Green & Co.).—The author is of the opinion that modern text-books on elementary physics are too mathematical and far too difficult to be mastered in one year by the average high school pupil. Therefore he has written a very elementary book which is based on the belief that the best methods of teaching the subject are as follows: "1. By a brief text for all of which the pupil will be held responsible, and, 2. By the addition of many interesting local applications to be supplied by both teachers and pupils." The diagrams are well drawn and the topics selected are very interesting. H. S. U.

8. *Die Messung vertikaler Luftströmungen;* by Paul Ludewig. Pp. 30, with 23 text-figures and 4 charts. Leipzig, 1911

(S. Hirzel).—The author describes in detail a self-recording anemometer which he designed especially for the study of vertical currents of air. This instrument, in conjunction with a Bestelmeyer variometer, was used throughout three free-balloon trips and the assemblage of apparatus gave very satisfactory results. H. S. U.

9. *The Teaching of Physics for Purposes of General Education;* by C. Riborg Mann. Pp. xxv, 304. New York, 1912 (The Macmillan Co.).—One of the liveliest themes of present educational discussion is that of the distinction between vocational and cultural work. This volume is the expression of an effort to show how, in the case of physics, the two points of view may be amalgamated into one. The subject-matter is divided into three parts. In the first part the development of the present situation is traced. The second deals with the origin of physics, and the attempt is made to establish the leading characteristics of this branch of science and to define its possibilities as a means of general education. In the third part the purpose of physics teaching is stated, and suggestions are made as to how this object may be attained. The index is immediately preceded by an alphabetical bibliography of the more important and easily accessible journal articles which have appeared during the last six or seven years and which are not mentioned in the main body of the book. The volume is of such pedagogical importance that it should, at least, be consulted by every conscientious teacher of the subject. H. S. U.

10. *Über Zerfallprozesse in der Natur;* by C. Engler. Pp. 33. Leipzig, 1911 (S. Hirzel).—This pamphlet is a revised account of an address made by the author on September 25, 1911 before the 83d convention of German scientists and physicians held in Karlsruhe. The conclusion finally reached is that, in all probability, the persistence of solar radiation, and therefore the existence and maintenance of all terrestrial life, is made possible by the disintegration of an "endothermic substance" in the sun and not to exothermic processes of combination, as was formerly supposed. H. S. U.

II. Geology.

1. *The Evolution of the Vertebrates and their Kin;* by William Patten. Pp. xxi, 1–486, with 309 illustrations. Philadelphia, 1912 (P. Blakiston's Son & Co.).—In this work Professor Patten sets forth most exhaustively his theory that the vertebrates arose from arachnid-like arthropods, basing his evidence upon comparative physiology, anatomy, embryology and paleontology. The essential features of the better known annelid theory are included in the arachnid theory, because both arachnids and annelids agree in the fundamental nature of their metameric structure, but, as Patten says, "when standing alone, the annelid theory ceases to be of value as a working hypothe-

sis * * * because we find no traces in the annelids of those illuminating modifications of metamerism so characteristic of the arachnids, and that afford us the required data for filling in, and explaining, the enormous gap between the unspecialized metameres of an annelid and the groups of highly specialized metameres in the head of a vertebrate."

"The tunicate, echinoderm, balanoglossus, amphioxus, etc., theories have similar inherent weaknesses, indicating that they must be subordinated to some larger view." These groups are therefore considered but degenerate offshoots of a common arthropod-vertebrate stock. One naturally looks on the arthropods as the probable ancestors of the vertebrates, because they are the most highly organized of segmented invertebrates and because the histological structure of their muscles, nerves, sense organs, cartilages, etc., closely resembles that of the vertebrates.

The problem Patten considers a perfectly simple one in principle although involving an enormous amount of detail in its application. "We have merely to strip off the superficial disguise of our hypothetical arachnid ancestors," he says, "and see whether either their underlying structure, their mode of growth, the general direction and historic sequence of their evolution, does or does not harmonize with the assumption that they are the ancestors of the vertebrates. We venture to state at the outset, that in our judgment they do harmonize with this assumption, and so fully and in such detail as to leave no other conclusion open than that the vertebrates arose from arachnid-like arthropods."

The nature of the evidence presented includes: A, cephalogenesis in arthropods; B, embryology; C, arachnid cephalogenesis prophetic of the vertebrate head; D, paleontology; and the range in its complexity can readily be understood by the following chapter headings: Outline of the arachnid theory; Evolution of the nervous system in segmented animals; Subdivisions of the brain; Minute structure of brain and cord of arachnids; Peripheral nerves and ganglia; General and special cutaneous sense organs; Larval ocelli and the parietal eye: The compound eyes of arthropods and the lateral eyes of vertebrates; The olfactory organs of arthropods and vertebrates; The functions of the brain; The heart; Early stages of arthropod and vertebrate embryos; The old mouth and the new, locomotor and respiratory appendages; Variation and monstrosities; The dermal skeleton; Endocranium, branchial and neural cartilages; The middle cord, the lemmatochord and the notochord; Ostracoderms and the marine arachnids; The ostracoderms; The vertebrates.

Part II discusses the zoological position of the Acraniata, including a contrast of craniates and acraniates; the Cirripedes, tunicates and echinoderms; the Enteropneusta, Pterobranchia, Polyzoa, Brachiopoda, Phoronida and Chætognatha; summary and conclusion.

The illustrations are beautifully done, being based upon marvellously detailed preparations as well as upon numerous models representing transitional stages and upon various specimens and

restorations of the extinct ostracoderms, which the author considers as representing an annectant but "entirely distinct class lying between the arthropods and vertebrates, and having some of the characteristics of each, but not truly belonging to either. Their supreme interest lies in the force they give to the suggestion that the vertebrates sprang from the arthropods."

Professor Patten has done a brilliant, painstaking piece of work, which will prove of great value as a contribution to the morphology and embryology of arachnids, ostracoderms, and vertebrates, whether his main thesis receives general acceptance or not. R. S. L.

2. *Die Wirbeltiere; eine Übersicht über die fossilen und lebenden Formen;* von Dr. OTTO JAEKEL. Pp. viii, 252; 280 text figures. Berlin, 1911 (Gebrüder Borntraeger).—Perhaps the most remarkable feature of this book is the taxonomic scheme which the author presents, in parts the most radical departure from the generally accepted classifications which we have seen. Briefly, Jaekel divides the Vertebrata into three "Unterstämme," Protetrapoda, Eotetrapoda, and Tetrapoda : the first including the tunicates, the second the fishes, and the third the higher forms.

The third Unterstamm, Tetrapoda, includes no fewer than seven classes with some curious transpositions of groups, such, for instance, as the inclusion in the class Paratheria of such orders as the Therapsidi, Testudinati, Anomodontia, Theriodontia, and monotremes!

This classification, extreme as it is, will find few supporters, as it implies phylogenies much at variance with the best opinion. Many of the illustrations, which are from various sources, are excellent, though very few were specially prepared for the book under review. Some of the author's original restorations, most of which have appeared elsewhere, are grotesque to say the least. R. S. L.

3. *American Permian Vertebrates;* by SAMUEL W. WILLISTON. Pp. 145, with frontispiece, pls. i–xxxviii, and 32 text figures, University of Chicago Press, Chicago, Ill., 1911.—This book, as the author says, "comprises a series of monographic studies, together with briefer notes and descriptions, of new or little-known amphibians and reptiles from the Permian deposits of Texas and New Mexico." The collections upon which the studies are based are mainly three: that of the University of Chicago made in recent years by field parties under the charge of Mr. Paul Miller or the author, earlier collections of the University of Texas made by Professor E. C. Case, and the great Marsh collection in the Peabody Museum at Yale, which proves an increasingly fruitful field for research as its varied treasures are brought to light. Professor Williston's work is offered more as a contribution to our knowledge of ancient reptiles and amphibians, with such summaries and definitions, based chiefly upon American forms, as our present knowledge permits, than as a final classification of these ancient forms. The illustrations of the work throughout were made by the author. R. S. L.

4. *Maryland Geological Survey* (Lower Cretaceous); Baltimore, 1911. 8vo, pp. 622 and 117 plates.—The fine series of reports on the Geology and Paleontology of Maryland, of which the volumes on the Eocene, the Miocene, and the Plio-Pleistocene have hitherto appeared, is here continued in a handsome fourth volume on the Lower Cretaceous, or Potomac Group, of the Maryland-Virginia area. The work forms one of the primary units in the elaboration of the continental geology, dealing fully and thoroughly as it does with the type sections for the Lower Cretaceous of the Atlantic border at their maximum of lithologic and paleontologic differentiation.

The Potomac Group is described physiographically by Messrs. Clark, Bibbins and Berry as a series of some 600 to 700 feet of estuarine fluviatile deposits resting on the old crystalline floor or "Weverton peneplain" on which important present-day drainage lines were already established. In general harmony with the continental border warp of the floor, the Potomac surface has a lessening slope to the southeastward. Three subdivisions each clearly separated by nonconformity are finally established, the Patuxent, the Arundel and the Patapsco; Patuxent-Arundel time being equivalent to the Neocomian and Barremian, and Patapsco time to the Albian following an Aptian hiatus.

The Arundel reptilia, mainly including the series of dinosaurians collected by Hatcher and studied by Marsh, are revised and re-illustrated by Professor R. S. Lull, of Yale University, who finds a distinct correlation with the Morrison of the West.

The limited invertebrate fauna of the Arundel and Patapsco is described by Professor Clark; while the main body of the volume is occupied by Dr. E. W. Berry in a restudy and illustration of the Potomac flora.

Following a survey of the Lower Cretaceous floræ of the world the Potomac plants are given a far more usable treatment than has hitherto been available to paleobotanists. For the *Cycadeoidea* types of the Patuxent (?) the diagnoses of Ward are conveniently retained. But it is held that the view of Wieland and others that such plants are very near the angiosperm (Ranales, etc.) line of descent "overlooks the wide difference in structure throughout the vegetative body, where the characters are much more conservative, and furnish a much safer clue to filiation than do the reproductive parts, especially when of the indicated plasticity of those of the Cycadophytes." The text is throughout illustrated by clear figures, and the excellent heliotypes of the early dicotyls of the Patapsco, the oldest of the continent, must hold high interest for botanists. G. R. W.

5. *A Method of Removing Tests from Fossils;* by S. S. Buckman (communicated).—A note under this title appeared in this Journal, August, 1911 (vol. xxxii, p. 163). By some accident, in the second line of the second paragraph the epithet "close-grained" was printed "coarse-grained." The present note is designed to call attention to this small error. A coarse-grained core is not at all

desirable for the process of removing tests by heat; in fact, a hard internal core which gives the best results has a grain of fine and close texture. A grain that is coarse is found in the cores of fossils from some of the Lower Oölites, when the rocks are truly oölitic; and such cores do not yield good muscle impressions, the core being only too apt to crumble away with the test. A coarse-grained core is found in fossils from some of the siliceous sands, like the Greensand; it may be coarse-grained and incoherent, so that when the test is removed the whole core crumbles and nothing remains. On the other hand, calcareous sands, and also clays, often yield specimens (Brachiopods) with good cores of close texture; it does not follow that, because the external matrix is soft and easily removable, the core will not be hard. Such matters are only to be learned by experiment. Some specimens explode when heated; this has happened with some phosphatized fossils, and with *Rhynchonellæ* from the white tufa of Württemberg. The loss among the latter from this cause was very considerable; but when the operation was successful the results were very interesting; the deep muscle-scars showing on the cores as raised lumps near the umbo are striking features.

Experience seems to show that in all cases the application of heat should be steady and gentle. If too fierce a flame be used, the tests do not seem to separate so readily from the core. Perhaps this is due to some sort of fusion taking place.

Thame, Oxon, England.

6. *Virginia Geological Survey;* Thomas L. Watson, Director. *Bulletin No. IV, The Physiography and Geology of the Coastal Plain Province of Virginia;* by W. B. Clark and B. LeRoy Miller; *with chapters on the Lower Cretaceous* by Edw. W. Berry and the Economic Geology by T. L. Watson. Pp. 274; plates I–XIX. Charlottesville, 1912.—Nearly twenty years' study of the Virginia Coastal Plain by Professor Clark, supplemented by detailed field work carried on in recent years by Professor Miller and by investigations of Dr. Twitchell, Mr. Berry, Mr. Vaughn, and others, has resulted in a very satisfactory interpretation of the physiography and geology of this province. Bulletin IV is, therefore, likely to become a standard reference text for the study of surface features, structure and stratigraphy of the entire Coastal Plains province from New York to Florida. The present report contains a descriptive bibliography of papers published between 1783 and 1911, a chapter on physiography (pp. 13–59), chapters on geology, including numerous sections, fossil lists, correlation and geological history of Cretaceous, Tertiary and Quaternary (pp. 59–222), and a chapter on Economic products (pp. 223–262). H. E. G.

7. *West Virginia Geological Survey;* by I. C. White, State Geologist. *Report on Jackson, Mason and Putnam Counties;* by Charles E. Krebs. 1911. Pp. xiv, 387; 3 maps, 31 plates, 5 sketches. Wheeling, 1911.—Consistent with the plan adopted by the West Virginia Survey, particular attention has been given

in the Jackson–Mason–Putnam county reports to features of economic interest. The chapter on soils (pp. 297–354) is sufficiently detailed to be of direct use to agriculturists; numerous oil and gas well records are given (pp. 200–246) and coal resources are studied in detail both as regards geological occurrence and the present state of the industry. In this connection the contour map of the surface of the Pittsburg Coal is of special interest. The geological map exhibits in a striking way the abandoned Teays valley and its relations to the Kanawha and Ohio valleys.

H. E. G.

8. *Wisconsin Geological and Natural History Survey;* E. A. BIRGE, Director. *Bulletin No. XXIV, Soil Series No. 1. 1911. Reconnoissance Soil Survey of Marinette County,* by SAMUEL WEIDMAN and PERCY O. WOOD. Pp. 44; 1 map, 4 plates, 1 figure.—In common with Bulletin XXXIII (this Journal, xxxiii, 382), the Soil Survey of Marinette county contains interesting geographic material, as well as data and recommendations of special interest to agriculturists. H. E. G.

9. *Building Stones and Clays:* their Origin, Characters and Examination; by EDWIN C. ECKEL. Pp. 264; 37 figures. New York, 1912 (John Wiley & Sons).—Most texts on economic geology include, with the strictly economic discussions, considerable matter better presented in standard texts covering a wider range of topics. The present book retains this characteristic of its class, and although designed to be of direct use to stone- and clay-working interests, yet several chapters in it might well form part of a general text-book for classes in elementary geology. Mr. Eckel has, however, succeeded better than most writers in separating "practical" discussions from matters of scientific interest, even calling attention to the uselessness of chemical analyses as tests for certain structural materials. The most distinctive features of the book,—the parts which amply justify its existence—are chapters on Field Examination and Valuation of Stone Properties, the Laboratory Testing of Stone, and Field Examination of Clay Properties. Rather full lists of references are given,—lists which would be of more use if classified according to quality or method of treatment. The object of including many pages of statistics of production for 1909 is not apparent.

H. E. G.

10. *Mineralogy;* by F. H. HATCH. Fourth Edition. Pp. 253; 124 illustrations. London and New York (Whittaker & Co., 1912).—In this fourth edition the author has rewritten and enlarged the volume first issued in 1892. The subject is briefly but clearly presented, the species described being, first, those important in rock formation; second, the ores of the prominent metals; third, the salts and useful minerals other than ores; fourth, gems. The introductory chapters discuss the general morphological, physical, and chemical properties of minerals.

III. Miscellaneous Scientific Intelligence.

1. *Annals of the Association of American Geographers;* edited by R. E. Dodge. Vol. I, 1911, pp. 1–164, with figures and plates.—The Association of American Geographers, organized in 1904, has now inaugurated a publication policy one of whose results is the above volume. It is proposed to publish from time to time certain of the most important papers presented at the annual meetings, and since the society is the only geographical organization which makes achievement in research a condition of membership, the Annals of the Association should be of unusual interest and value. The present volume is of special importance to librarians and geographers, for it contains titles and abstracts of all papers presented to the society (1904–1910 inclusive) and heretofore not published or published in variable form in different journals.

Under the circumstances, certain features of the make-up deserve attention. We note with satisfaction the quarto size of the volume which permits the presentation of large-scale maps, sketches, and photographs and a dignified text-page. Everyone agrees that octavo size is perhaps a little more convenient, a fact that has begotten a school of extremists who will not have quartos under *any* circumstances. Foot-note references are another praiseworthy feature. The inconvenience of reference from page to notes at the end of a volume and back again is so great that there seems to be no compensating advantage in their separation. The time has passed when this can be called a difference of opinion; it is the difference between good and bad judgment.

The papers in Volume I are well chosen and represent something of the range of modern geography: "The Causes of Vegetational Cycles" (Cowles); "The Colorado or Front Range: A Study in Physiographic Presentation" (Davis); "Geography in the Development of the Alaska Coal Deposits" (Brooks); "A Geographic Study of Mesa Verde" (Atwood). Cowles' paper is not only a model in clear scientific writing but also a revelation to many of the value of geography in ecological research. As indicated by the sub-title, the second paper is concerned primarily with form in physiographic writing and embodies in final form the ideas presented in Professor Davis' recent papers on this subject together with certain new features as to method. It is an extraordinarily useful and brilliant essay that, we venture to say, will be as eagerly read a hundred years hence as now. Brooks' paper is a closely organized study in the economic geography of the Alaskan coal fields. Atwood discusses the origin of Mesa Verde and the relation of its physiographic character to the homes and activities of the Cliff Dwellers. I. B.

2. *Annual Report of the Director of the Field Museum of Natural History*, Frederick J. V. Skiff, *for the year 1911.* Report series, vol. IV, No. 2; pp. 101–182, plates XVII–XXIX. Chicago, January, 1912.—The Annual Report by Dr. Skiff states that the past year has been an important one for the Field

Museum of Natural History in Chicago, since the site for a new building in Jackson Park has been accepted by the trustees. Further, the plans for the new building in all their details have been completed and approved, and the articles of specification for the contracts also drawn up. This represents the results of six years' work, and when the transfer is accomplished, the collections will have a permanent and safe home. The Museum has been active, not only in extending its collections and developing its exhibits, as detailed and illustrated in this Report, but also in various expeditions to distant points. There are here included the Meek expedition to Panama and the Osgood expedition to Venezuela. Further, Dr. B. Laufer, after an absence of three years in the far East, has returned bringing upwards of 10,000 ethnological specimens from Tibet and China; this collection is now being installed, and a Museum publication on jade, by Dr. Laufer, is promised. A botanical expedition has also been under way, since last August, in the northern tropics and the far East.

It is also announced that a contribution of $250,000 has been made by Mr. Norman W. Harris for the extension of the work of the Museum into the public schools of Chicago. The total sum expended in the year for the maintenance of the Museum amounted to $150,000, to which must be added about $50,000 more for cases, expeditions and collections.

3. *The Science Reports of the Tôhoku Imperial University, Sendai, Japan.* Vol. I, No. I; pp. 1–66 with 8 plates.—The University at Sendai, Japan, has recently established a series of Science Reports, of which No. 1 is now at hand. Professor Hayashi, the librarian of the University, is head of the publication committee and communications in regard to the publications should be sent to him. To the present number he contributes two mathematical articles, and in addition there is a paper (pp. 1–42), by Professor K. Honda on the thermo-magnetic properties of the elements. This investigation has been extended to 43 of the 81 elements, and the results are given in full, with the aid of six plates. The oxidation of aniline III is discussed by R. Majima, and a brief paper on the secondary undulations of the Canadian tides, by K. Honda and W. Bell Dawson, closes the number.

4. *Fourth Report of the Wellcome Tropical Research Laboratories* at the Gordon Memorial College, Khartoum; ANDREW BALFOUR, Director. Vol. B, General Science. Pp. 334, with numerous maps, illustrations, and colored plates. Department of Education, Sudan Government, Khartoum, 1911.—The March issue of this Journal (p. 294) contained a notice of the medical volume of this report. The companion volume on general science contains some sixteen fully illustrated articles on a variety of topics, written by members of the staff and other specialists. The principal papers discuss the chemical analyses of soils and products; gum production; insects injurious to man, animals, and crops; birds; scorpions; snakes; protozoa; gold mining; tribal customs; and municipal engineering. W. R. C.

5. *The Life and Love of the Insect;* by J. HENRI FABRE; translated by ALEXANDER TEIXEIRA de MATTOS. Pp. x, 262, with 12 plates. London, 1911 (Adam and Charles Black).—English readers who are unfamiliar with the French language and who have a taste for natural history stories will appreciate the translation of this volume of essays selected from the voluminous writings of this "Insect's Homer," as the author has been called. In the keenness of the observations described and the vividness of the language used the ten or more volumes of *Souvenirs Entomologiques* are unequaled by any scientific production of recent years. The stories of the life and love of the insect are made to possess an interest to the sympathetic reader fully equal to that of an imaginative novel, and yet each statement rests upon the actual observation of the writer.

This little volume consists of eighteen essays, of which ten describe the natural history of various species of elsewhere prosaic dung-beetles, the remaining chapters dealing with wasps, bees, weevils, and scorpions. The translation has been well done. W. R. C.

6. *The Evolution of Animal Intelligence;* by S. J. HOLMES. Pp. v, 296, with 18 figures. New York, 1911 (Henry Holt & Company).—The subject of animal behavior and intelligence has been one of the latest of the biological studies to receive sufficient attention to be classed as a science. The writer of the present book has done good service in presenting the subject in the stage of development which the study has now reached. One quickly notes the experimental attitude of the observer free from prejudice in place of the older anthropomorphic explanation of an animal's behavior.

In his treatment ot the subject the writer first discusses simple reflexes and tropisms and the behavior of the protozoa. Then follow chapters on instincts and modifications of behavior, pleasure, pain, and the beginning of intelligence, leading finally to the mental life of monkeys. It may be of interest to note that the author assumes that the step from simple instincts to the formation of associations by experience, that is, intelligence, has been taken many times in the course of evolution. He considers the crustacea and mollusks as the lowest phyla of animals in which intelligence can be satisfactorily demonstrated. W. R. C.

OBITUARY.

Professor P. N. LEBEDEW, the Russian physicist, died in March last.

Professor AUGUSTE TÖPLER of Dresden, the inventor of the Töpler mercury pump, died in March at the age of seventy-six years.

Professor EDWARD DIVERS, from 1873 to 1899 Professor of Chemistry in the Imperial University, Japan, died on March 8 in his seventy-fifth year.

Mr. GEORGE BORUP, a member of the Peary North Pole Expedition and himself planning, with Donald B. MacMillan, an expedition to Crocker Land the coming summer, lost his life by drowning on April 28.

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* This Index contains the general heads, CHEMISTRY (incl. chem. physics), GEOLOGY, MINERALS, OBITUARY, ROCKS, and under each the titles of Articles referring thereto are mentioned.

GEOLOGICAL REPORTS.

GEOLOGY.

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